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DECEMBER, 1942

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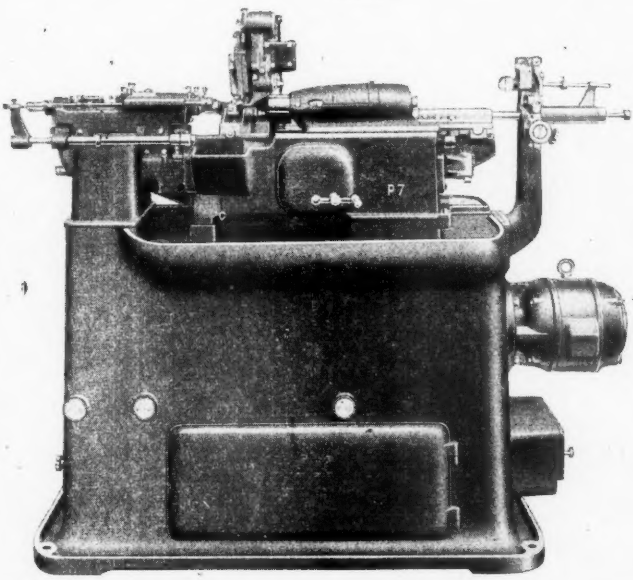

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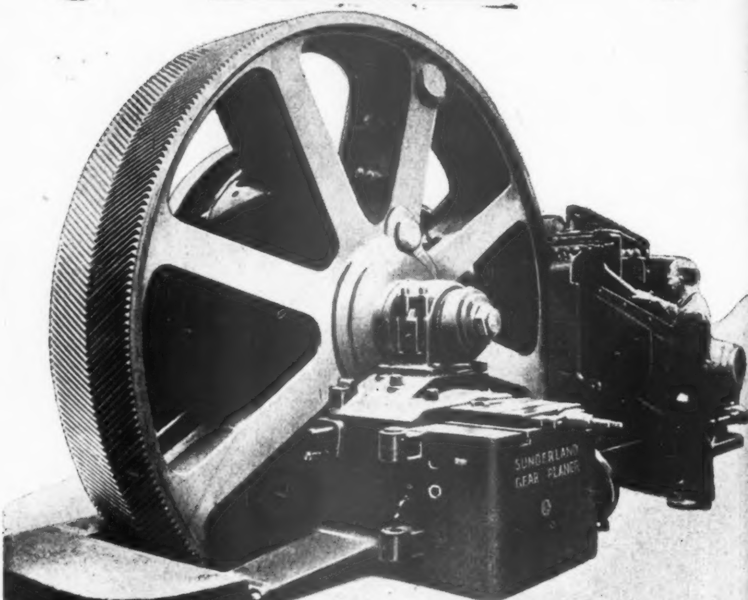
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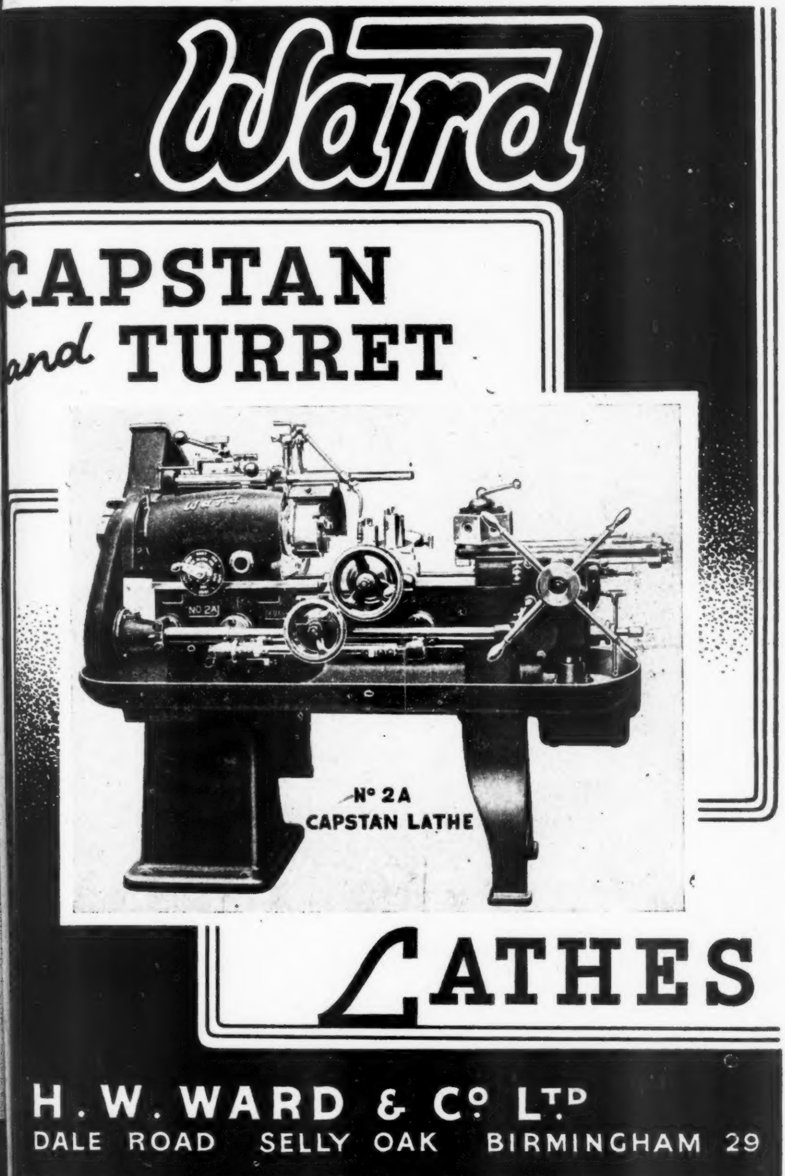
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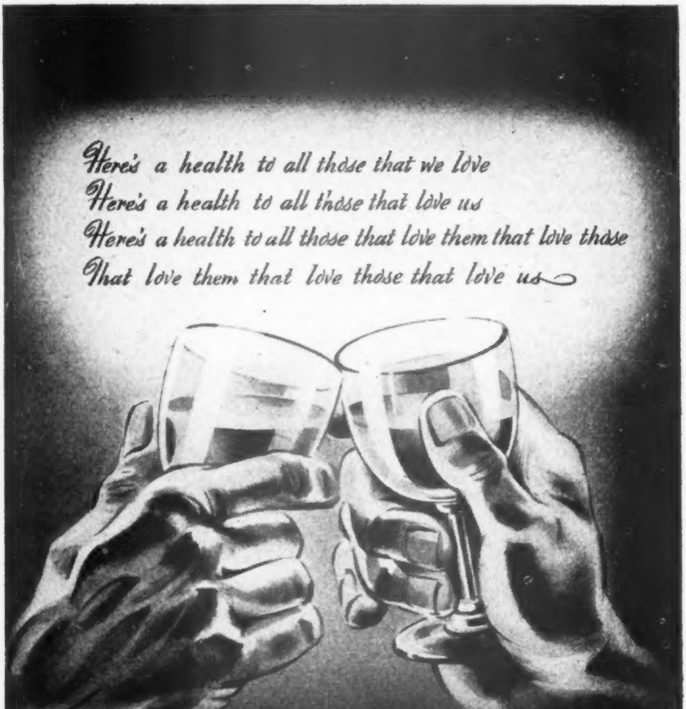
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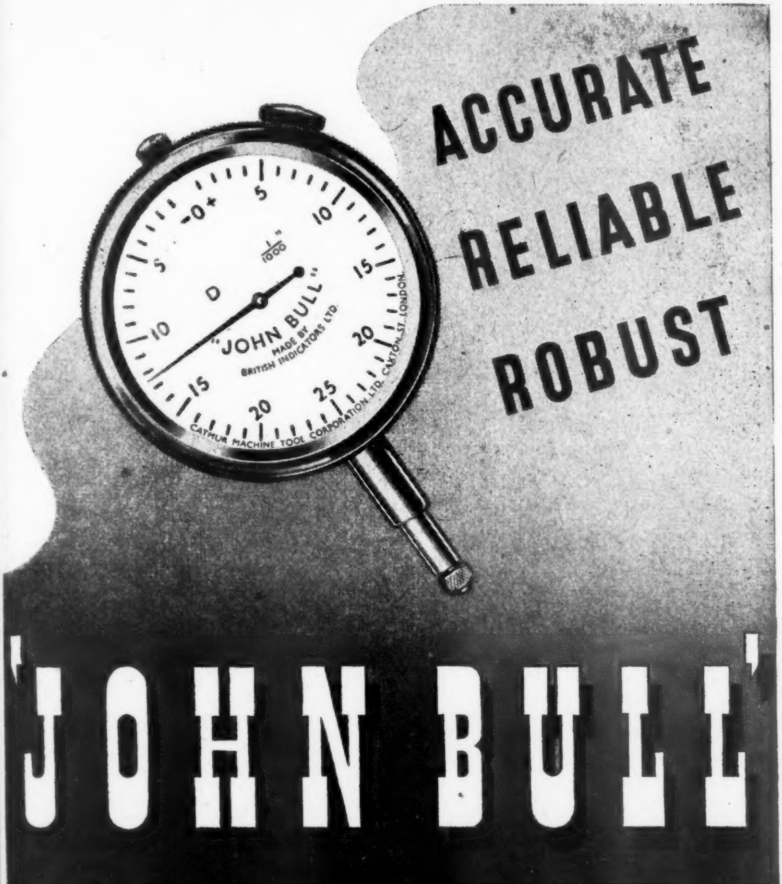
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INDEX TO ADVERTISEMENTS

As a war-time measure the advertisement section of this Journal is now published in two editions, A and B. Advertisers' announcements only appear in one edition each month, advertisements in edition A alternating with those in edition B the following month. This Index gives the page number and edition in which the advertisements appear for the current month.

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "The Journal" should not be taken as an indication that they are necessarily available for export.

INSTITUTION NOTES

December, 1942

Fixtures.

January 16—Yorkshire Section. Lecture on "Production Control" by R. Appleby, A.I.P.E.

Meeting of the Council.

The Council met in London on Friday, December 18, 1942. Present: Mr. H. A. Hartley, Chairman of Council presiding. The following Members of Council attended: Messrs. J. E. Baty, J. W. Berry, J. H. Bingham, J. E. Blackshaw, R. Broomhead, J. S. Daniels, W. F. Dormer, H. A. Drane, E. P. Edwards, J. France, G. H. Hales, F.W. Halliwell, S. R. Howes, E.J.H. Jones, J.T. Kenworthy, R. Kirchner, Major C. W. Mustill, J. R. Pearson, R. D. G. Ryder, Dr. H. Schofield, Mark H. Taylor and F. C. White, also present: Messrs. A. L. J. Brain and A. L. Stuchbery (London Committee) and Mr. John Vaughan (Secretary, South Wales and Monmouthshire Section).

Newly Elected Members.

As Members: M. F. Bellwood, W. Bentley, W. A. J. Chapman, J. K. Clegg, J. T. W. Dewar, F. W. H. Lee, F. C. Newman, F. Ricks, C. Stain, F. G. Thorpe, F. C. Tudball, R. O. D. Wilkinson.

As Associate Members: C. M. Anderson, D. E. Austin, H. W. J. Abbey, W. D. J. Annear, A. G. Burton, A. E. Balchin, C. O. Brooks, S. L. Cook, J. A. T. Crump, C. H. J. Cooper, C. E. Eavis, G. E. Field, G. W. Green, B. G. Horstmann, L. Harper, A. H. Leggett, L. S. Leese, F. Lee, A. Mitchell, A. Michie, A. G. Marshall, H. Newham, J. G. Nickson, E. J. Napier, J. T. Pallett, R. H. Pulfrey, E. R. J. Randall, G. A. Saville, W. H. J. Stockley, A. Smith, H. B. Thomas, H. L. Thomas, S. R. Trevillion, W. Winters, F. Walker, G. H. Wilson, S. G. Young.

As Associates: H. Bradburn, G. Fefer, C. G. Heys-Hallett, W. T. Johnstone, E. R. Jacobs, J. F. Kayser, D. A. Miller, E. Overend, L. W. Robson, P. J. Swales, B. W. J. White.

As Intermediate Associate Members: K. Archer, R. Ardaillon, C. J. Atkins, H. Bury, A. E. Bebbington, D. C. Curwen, B. E. Curran, W. R. Chambers, R. P. M. Cullingford, A. Chadwick, P. H. Cook, L. G. Carver, F. A. Eastwood, J. W. East, F. E. George, N. E. Hodge, E. E. Hempsall, V. A. Hayward, J. S. Hopkinson, E. A. Handscomb, A. Larnder, W. Mayall, A. H. Macbeth, D. Moffat, W. B. Nivison, F. H. Nash, H. J. Nunn, H. J. O'Neill, C. J. Parnaby, L. R. Pike, R. E. Riederer, W. A. Sykes, R. E.

Scott, A. J. Smith, R. A. Spencer, D. J. Sinclair, A. K. Tyreell, W. Tanner, J. W. Weston, A. D. White, W. G. Wyman, T. G. Wrighton.

As Graduates : G. P. Archibald, J. H. Ayre, W. J. Armstrong, A. Beaumont, J. Beresford, W. H. Boswell, K. A. Bowker, F. C. Coupe, S. T. Cutmore, E. Darwin, J. France, W. C. Gillam, R. T. Hurst, E. W. G. Harris, J. W. E. Hearn, W. H. Jackson, C. S. Kent, H. Kohn, A. F. Lovatt, E. Miller, E. L. Stead, R. F. Thompson, H. G. Whittaker, W. York.

As Students : R. W. Bulpitt, R. Blore, R. E. Baldwin, B. Baker, A. A. Barrett, E. H. Cutts, M. Cohen, G. W. Crowther, J. A. Clegg, J. P. Clapham, C. L. Chopin, R. C. Dobbs, D. W. Emery, W. F. Fisher, W. Feder, P. Glaser, H. Gray, L. Hopwood, P. S. Halton, W. L. Hodgkinson, J. Irwin, J. A. Ireland, D. R. Maude, N. A. Miller, F. A. Mellors, D. A. Monger, A. D. McLean-Hill, J. W. Munro, D. H. Norcross, M. S. Nall, G. D. Newell, C. H. Parker, J. G. Patrick, H. R. Pendergast, L. H. Tuck, D. K. Wood, L. A. Waters, J. Winter, G. W. Wilmersdoerfer, P. Whiteley, B. H. Watkins, H. Ward, G. E. Wells.

As Affiliated Firms : Clarkson (Engineers) Ltd. ; Forgrove Machinery Co. Ltd. ; The Selson Machine Tool Co., Ltd.

Transfers.

From Associate Member to Full Member : C. T. Barton, E. R. Francis, F. P. Laurens, R. Swift, P. J. Westcott.

From Associate to Full Member : H. Orenstein.

From Intermediate Associate Member to Associate Member : H. C. Chapman, A. A. Gilbert, N. Noake, R. Rhymes, L. R. Ward.

From Graduate to Associate Member : H. Coulthurst, J. G. Norris.

From Graduate to Intermediate Associate Member : H. S. Franklin, J. Knight, T. J. Suffolk, O. A. Walden.

From Student to Graduate : H. F. Box, N. Sykes.

Higher National Certificates in Production Engineering : first list of passes.

The Joint Committee for Higher National Certificates for England and Wales announces that the following candidates have qualified for Higher National Certificates in Production Engineering :

(*a*) *Northampton Polytechnic Institute, London.* William A. Beattie, William F. Bennett (with distinction in Electrical Technology), George D. Cohen, Samuel Death, Thomas G. Fisher, Alfred W. Millet, Max E. Schneider.

(*b*) *Keighley Technical College.* Harry Bailey, Donald Potter, John Speak.

(*c*) *Loughborough College.* The list will be reported later.

THE PRODUCTION OF STEEL CASTINGS

Paper presented to the Institution, Yorkshire Section, by F. W. Rowe, B.Sc.

MOST engineers have a fairly clear idea regarding the general methods used in making steel castings. It is not my intention, therefore, in a short paper such as this, to give particulars of methods, either of steelmaking or founding, which can be found in any standard textbook on the subject, but rather to touch on some points which are likely to create an appreciation of the possibilities of steel founding and where an understanding of the difficulties of both the steel founder and the engineer would be to the benefit of both. I am well aware that steel castings were, up to recent years, viewed with some suspicion by engineers on account of the variability in quality which was likely to be found, particularly in regard to general soundness. This suspicion was quite justified. The quality of steel castings in general had not been up to recent years, of a standard which would justify engineers taking the fullest advantage of their possible uses. The causes of this standard of quality were largely economic within the industry, but in recent years much has been done to create new confidence both within and without the industry, and there is no doubt that future years will see a much wider use of steeel castings and a greater reliance on their quality and performance created in the minds of engineers.

Steelmaking Processes.

Steelmaking processes for steel for castings are generally similar to those for ingot steel, and the best practice for one is the best practice for the other. While the steelmaking process has undoubtedly an influence on the quality of steel casting produced, its effect is by no means so marked on quality and soundness as other portions of the steel founder's art. As will be mentioned in greater detail later, the soundness and quality of the casting depend to a much larger extent on methods of moulding and, in particular, measures to compensate for liquid shrinkage, than on the process used for steelmaking.

It is, however, universally acknowledged nowadays that the highest quality of steel, whether for ingots or castings, is produced

Leeds, February 14, 1942.

in the basic electric arc furnace. This does not mean that the basic electric arc furnace, or any electric furnace, cannot produce bad steel; in fact I might go so far as to say that there has been as much bad steel produced in electric furnaces as in any other type, but there is no doubt that the basic electric furnace, properly worked, produces a quality of steel which is superior to that from any other process. The basic electric furnace also has the advantage that it can produce any analysis of steel satisfactorily, and is therefore more flexible from an analysis standpoint than any other process.

Probably the next best process, purely from a quality of steel standpoint, is the high frequency electric furnace which is being

Fig. 1.—8-ton basic arc electric furnace.

ever more widely used for lighter castings and in the production of high quality ingot steels such as high speed steel and stainless steel. It possesses the advantage of flexibility plus ease of quality control.

Next in order of steel quality come the acid open-hearth and the acid electric processes, both of which are fairly similar in regard to the quality of steel they can produce, the acid electric having some advantage in that hotter steel can be made to cater for lighter castings and more complete deoxidation of the steel can be made. In both acid electric and acid open-hearth furnaces one is largely dependent on the quality and purity of the raw materials.

Next in order of quality comes acid converter or Bessemer steel, represented in steel founding usually by the Tropenas and Stock converter processes. Here flexibility as regards analysis is limited and the steel, even when made to the best advantage, is richer in oxides and gases than a well-made steel from other processes.

Converter steel has, however, advantages in another direction, in that the steel is usually extremely fluid and retains its life in the ladle well, which does help in producing castings free from shrinkage defects. Like the acid electric and open-hearth processes, acid converter steel depends as to its ultimate analysis a great deal on the analysis of the raw materials used, and very low sulphur and phosphorus contents are difficult to obtain as a commercial proposition. Alloy steels are not, with the exception of 14 per cent manganese steel, usually produced by the converter process. The modern tendency in steel foundries, partly dictated by economic considerations and partly with the object of realising higher quality or obtaining greater flexibility, has been towards new installations

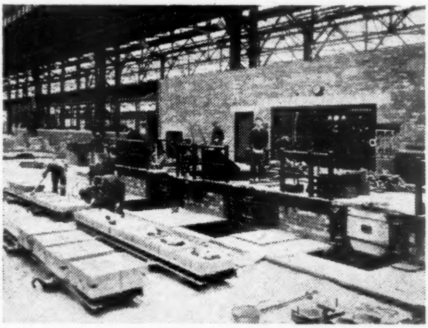


Fig. 2.—550 kVA high frequency melting unit with bodies of 30 cwt., 15 cwt. and 5 cwt. capacity.

being largely electric furnaces, and there does not seem to be any doubt that this tendency will persist.

There is, however, another angle to this question of the quality of the steel which is used for making castings. This is the uniformity of quality which may be expected from different processes. While each process may be capable, under skilful manipulation, of giving high quality steel, different processes do vary in their liability to produce unsound steel, *i.e.*, steel which is " wild " and gives up gases on solidifying in the moulds, causing blowholes and sponginess. From this point of view also the steelmaking processes can be grouped in the same order as that given. Basic electric steel is probably the least liable to occasional poor heats and converter steel the most liable. These occasional " wild " heats, which sometimes happen even in the best regulated foundries, come without warning. The steel appears all right in the ladle and the castings on superficial examination look sound. After annealing and shotblasting, how-

ever, numerous pinholes appear on the surface or on machining holes are shown varying from pin heads to blowholes ¼ inch or more in diameter. It is not suggested that all blowholes are due to "wild" steel, *i.e.*, steel which gives up its gases (chiefly hydrogen) at the moment of solidification, as they may also be due to damp moulds or moulds which are badly vented, but a large proportion of such defects are due to poor steel.

Moulding Methods.

Steel castings are made in sand moulds of two types ; greensand moulds, with sand containing 3 to 5 per cent of moisture, and dry sand moulds, where the moulds are made with damp sand but subsequently stove dried to expel all the moisture.

The sand used in both cases is either a pure silica sand or one containing a high proportion of silica. Sands for steel moulding must be highly refractory, as the pouring temperature of steel is very close to the sintering temperature of all commercial refractory materials, and even with the best sands a certain amount of fusion between the steel and the sand always takes place in difficult portions of the mould, such as those portions adjacent to the runner. Greensand moulds are more largely used for castings of no great weight and of light section, and dry sand moulds for the heavier and more important work. It is generally conceded that there is more risk of defects in medium and heavy castings with greensand moulding, but with the greater attention paid in recent years to sand properties and sand control, the range of castings which can be cast in greensand moulds has been enormously increased. By controlling the moisture content, bonding material strength and permeability of the sand, and working under standardised conditions, there is nowadays no greater risk with greensand moulds than with dry sand within the field of castings for which they are suitable, and the greensand method has advantage over dry sand method in cost and other directions.

In addition to these two methods of producing moulds, there is also the Randupson process of cement bonded sand, where all the advantages of a dry sand mould are obtained at less cost and without using steel or cast iron moulding box parts. The Randupson process gives a mould of much higher strength than greensand or dry sand with as high or higher permeability, and with thus less risk of scabs or blowholes and a casting which is truer to pattern, particularly in medium and heavy castings. Cement-sand mixtures are most suitable for medium and heavy work.

Runners and Feeding Heads.

That phase of the moulding process which influences to a larger degree the soundness and quality of the castings produced is the

method of running the casting and, more important still, the provision for liquid shrinkage. No other portion of the steel founder's art has so much influence on the resultant quality of the casting, and it is here where the skill and experience of the steel founder is most needed. Steel has a far higher liquid contraction than most cast metals, and has a high contraction after it has solidified. Volume contraction in the liquid state and during solidification varies (chiefly according to the casting temperature) from 5 to 7 per cent, and during cooling down after solidifying about 4 per cent. In addition to porous spots caused by inadequate compensation for liquid shrinkage, cracks and tears can be very prevalent if suitable means are not adopted in moulding to avoid them. Properly catering for liquid shrinkage in steel castings is an expensive matter. The net yield on steel castings, *i.e.*, yield of good castings produced to metal melted, is, in average work, not much higher than 50 to 55 per cent. On heavy work the yield is somewhat higher than this, but on light work it may be less. That is, for every 100 lb. of metal melted, only 55 lb. of steel castings are produced. Since molten metal in the ladle costs £10 to £15 per ton, and the feeding heads after being removed are only worth £4 to £5 per ton, it will be seen that the cost of providing adequate feeding heads forms an appreciable proportion of the cost of making a steel casting. In addition, of course, the heads have to be cut off and the place where they have been, ground down or otherwise dressed. There is always a temptation, therefore, for the foundryman to increase his yield. Whilst much may be done in this direction by proper design of castings and careful study of shrinkage phenomena, there is no doubt that a great many of the shrinkage cavities and porosity found in steel castings are due to inadequate feeding heads or feeding heads badly designed or put in the wrong places.

Design for Steel Castings.

Every foundryman will agree, however, that many of the steel castings designed by engineers are such that it is an almost impossible task to secure a perfectly sound casting. Engineers can be of the greatest help, both to the steel founder and themselves, in studying carefully the design of new castings from the founder's point of view, and in the alteration of design of castings which have proved troublesome. It is admitted that relatively little information on the effect of design has been put in the hands of the engineer, and such will only come from co-operative effort. The interest of engineers in steel casting design has been aroused in recent years, and the increasing use of steel castings, and the heavier demands which are now being made arising out of more exacting needs, have all helped in this direction.

In addition to the troubles which may arise due to liquid shrinking, appreciable changes in section and sharp angles contribute to uneven contraction of the steel after solidification and frequently cause hot tears or cracks to form after the casting has solidified. It is appreciated that it is impossible to design castings with even section throughout except in the simplest cases, and it is also impossible to eliminate by design all stresses which might cause a casting to tear after solidification, but considerable improvement can be effected and thus make it easier for the foundryman to produce a casting completely solid and free from contraction tears and stresses.

Any portion of a casting which is thicker than the general section is a potential source of either a shrinkage cavity or a crack or tear.

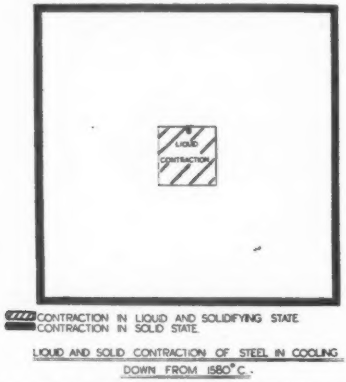
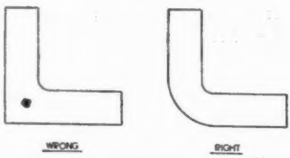


Fig. 3.—Diagrammatic illustration of liquid and solid contraction in steel.

Obviously the thickest portions of the casting are those which are the last to solidify, and it will be these that contain shrinkage cavities unless they are fed from a head containing still liquid metal. Again, they will remain hotter than other portions of the casting in cooling down, causing unequal contraction and the liability to cracks or residual stresses. Junctions of one portion of a casting with another, unless carefully designed, are potential sources of weakness. For instance, the common right angle junction between one portion of the casting and another is always a source of trouble if not properly designed. Figure 4 shows a common type of junction which, unless fed with a separate head at the thickest section, will show a cavity or porous spot as indicated. The design shown alongside (though it is agreed that such a perfect design may not always be suitable) correspondingly can give no

trouble and is just as strong as the more common type shown on the left. Although the cross section of the good design is smaller than that shown in the bad, greater confidence can be placed in it because of its complete soundness.

Where " T " sections and " X " sections are used in castings,



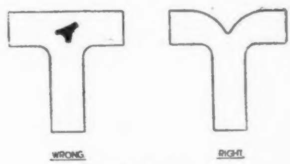
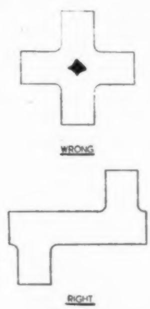


Fig. 4 Fig. 5

Fig. 4.—Right angle junction showing cavity which occurs unless properly fed.
Fig. 5.—" T " section showing cavity which occurs in normal design and design which eliminates cavities.

the design, wherever possible, should be modified to prevent the mass of metal which obviously hollows such a junction. Figure 5 shows the normal design of a " T " section, and on the right a much more suitable design, while Figure 6, left, shows how " X " sections should be disposed to give soundness of metal without trouble to the founder. Designs are often encountered in which an area of heavy metal is attached to all sides to metal of lighter section and so located that the foundryman has no opportunity to



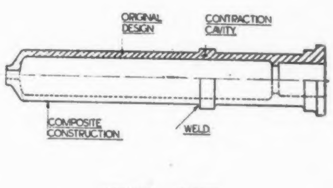


Fig. 6 Fig. 7

Fig. 6.—" × " section showing cavity which occurs in normal design and design which eliminates most of the cavities.

Fig. 7.—Hydraulic design showing (a) top half, original design giving contraction cavity, (b) bottom half, corrected design with ring welded on.

put a feeder head to compensate for liquid shrinkage in this portion. Such a design is a difficult problem for the steel founder and should be most carefully studied to see if some coring out to lighten the

section cannot be made, or if the section at that point cannot otherwise be made lighter.

Figure 7 shows a hydraulic cylinder in which this design defect is apparent, whereas a much better design would be to use a rolled steel ring welded on separate from the casting afterwards. The extra thickness of metal at the mouth of the cylinder is usual and causes no difficulty since at this portion of the casting a head can be, and is, placed in any case, and is helpful to the feeding of the lower portions of the casting.

Closing and Casting.

After the moulds and cores have been made, the complete mould assembly is done in an operation known in the foundry as " closing." The boxes are weighted or clamped to prevent the metal running out and the complete mould cast. For all except the lightest castings, the best steel foundry practice is to use a bottom pouring ladle to eliminate the possibility of slag going in with the steel. All castings up to about one ton in weight, except those of delicate section, can be knocked out immediately ; in fact, if there is any heavy coring it is desirable to do so to relieve contraction stresses.

Shotblasting and Dressing.

The next operation is to shotblast the castings, or at any rate clean round the heads, so that they can be burnt off with an oxy-acetylene torch prior to annealing or other heat treatment. If possible, also, any minor defects that are apparent should be repaired by welding at this stage. Engineers often hold up their hands in horror when they hear that steel castings have been welded, although they apparently gladly employ a completely fabricated structure, where the whole of the strength depends on welding, without any misgivings.

If the surface appearance of a casting indicates that it is possible a defect may lie under the skin, it is far better to cut this out fully and weld than to ignore or hammer over the defect. Small tears and cracks are similarly dealt with, these being fully bottomed with pneumatic chisels and welded with metal of the right composition.

Heat Treatment.

Carbon steel castings and most alloy steel castings are then annealed. The mechanical properties of steel castings as regards tensile strength, elongation, reduction of area and impact strength are to a very large extent dependent on the thoroughness with which the heat treatment, whether it be annealing, normalising or hardening and tempering, is carried out. The condition of the steel in the " as cast " state has the poorest mechanical properties and consists of large crystals. Annealing at temperatures from 900 to

1100° C, dependent on the type of steel, for the requisite period of time dependent on the thickness of the casting, removes this coarse structure by recrystallization and substitutes a fine grained structure. While the term annealing (which means cooling down slowly in the furnace after maintaining a high temperature) is commonly used, most castings benefit from being cooled in air after annealing rather than slow cooled in the furnace. Very large castings, or castings with great variation in section, where contraction stresses may be set up by differential cooling, are an exception to this rule, but where normalising is practicable a rather higher tensile strength a smaller grain size, and higher shock strength are obtained with very little, if any, reduction in the ductility. Again, while hardening and tempering are commonly only used with alloy steel castings, most carbon steels would benefit from this treatment in the same manner as forged steels.

Greater realization of the importance of the annealing, normalising, hardening and tempering operations (the exact treatment

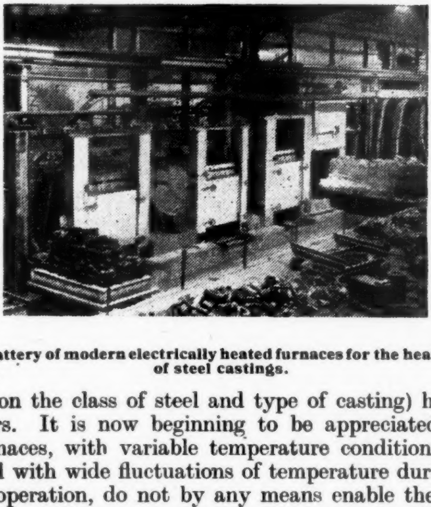


Fig. 8.—Battery of modern electrically heated furnaces for the heat treatment of steel castings.

depending on the class of steel and type of casting) has arisen in recent years. It is now beginning to be appreciated that antiquated furnaces, with variable temperature conditions inside the furnace and with wide fluctuations of temperature during the heat treatment operation, do not by any means enable the founder to realise the best physical properties of the steel. In particular, the shock strength of the steel is likely to suffer from haphazard heat treatment, which is the only heat treatment possible with many old designs of furnaces.

Furnaces for the heat treatment of steel castings should be as rigidly controlled, both for time and temperature, as any other

metallurgical heat treatment. The rate of input of heat should be controllable and the maintenance of specified temperatures within close limits should be easy and practicable, and preferably automatically controlled. These conditions are most easily obtained and best realised in an electrically heated furnace, but, with care, equal results can be obtained in gas fired furnaces. The difficulties in this direction are much enhanced in solid fuel fired furnaces.

The illustration in Figure 8 shows a portion of a battery of modern electrically heated furnaces for the annealing and other heat treatment of steel castings. The furnaces have bogie hearths and automatic temperature control, and the rate of heat input can be varied to suit any metallurgical requirements.

Similarly, if castings are to be oil or water quenched and tempered, proper designed tanks with circulating and refrigerating systems are needed. It is not sufficient to dump the castings into a tank of oil or water. The oil or water must be circulated at a definite speed through the tanks, not merely to prevent excessive temperature rise in the quenching medium but to ensure fresh cool oil or water constantly passing over the surface of the castings.

Final Dressing.

After the annealing treatment, castings are again shotblasted and thoroughly dressed with portable and fixed grinding wheels and pneumatic tools.

The labour costs for these operations are usually more than any other single labour cost. All fins, flash, and joint marks are removed and all burnt-on sand which has not been moved in the shotblast operation. Castings which afterwards have to be heat treated are then subjected to the final hardening and tempering operations, and are then ready for final inspection.

Alloy Steel Castings.

Increasing use is being made by engineers of alloy steel castings, and the saving in weight and the greater load carrying capacity which can be secured by alloy steel castings, is being steadily appreciated. An alloy steel casting, properly made and heat treated, has physical properties quite as good as a forging of the same composition, and, whilst it is expensive to achieve the same degree of soundness, this can be done and often results in a much cheaper finished article.

Where the strength of a forged steel is required, such should not be made as castings where simple forgings or die stampings can be used, but in a great many cases the shape which the designer requires cannot be secured from a forging except by very excessive man-hours in machining, and here it is always worth while to investigate the cost of a steel casting in terms of the finished product,

i.e., whilst a steel casting may, judged on price per cwt., be very much more expensive than a normal steel forging, the fact that greater latitude in shape and design is permissible very often means that a properly heat treated alloy steel casting will fulfil a duty where no other type of construction is possible. For these particular duties it is more than desirable that the founder should have an opportunity of co-operating in the design, and a certain amount of experimentation may be needed for new designs.

Inspection, Testing and Control of Steel Castings.

The quality of steel castings is to a large extent dependent on the care and control exercised during manufacture and the data furnished by constant inspection of the finished product and its use for future guidance. Practice in steel foundries varies, dependent greatly on the type, difficulty and service requirements of the castings they produce. Obviously those foundries who are able to undertake the varied class of work, both as regards analysis, physical properties and type, and who cater for the most difficult castings, have facilities and organisation for inspection and control far in advance of foundries doing relatively unimportant work in the cheaper fields. Those in the former class have research, laboratory, technical and inspection costs equal to 4 to 6 per cent of the value of the turnover, but such costs are amply repaid in greater realiability of the product and the more ready demand their products command, and in a less number of complaints and rejections from customers.

Metallurgical Controls.

In a large measure, to secure standardisation and increase the quality of the castings, the controls are in the hands of a technical staff. An important part of the controls is that concerned with the quality of the steel. This is naturally more extensive if the foundry is making a number of types of steel and by different processes. For instance, in the basic electric arc furnace, where raw materials are largely scrap, incoming scrap has to be graded for analysis and type, and a watchful eye kept on the segregation of heads and runners in different parts of the foundry. As soon as the bath is melted a sample is taken and analysed for at least carbon and phosphorus, so that the metallurgist in charge of the furnace can see that the carbon content lies within the specified limits to secure proper reactions during the " oreing-down " period, and that the oxidising lime slag is doing its work properly in removing phosphorus. From the same sample the manganese content is estimated, and if the steel is an alloy steel the analysis of the alloy elements obtained from the scrap is done. Speed is very essential at this stage to guide the melting shop staff, and it is usual to furnish the carbon

and phosphorus estimates within 15 minutes of a sample being taken, and the other elements within 30 minutes. If insufficient reduction in phosphorus is being obtained the first oxidising slag may have to be taken off and a new lime slag substituted, in which case a further bath sample is taken before changing the slag to the deoxidising or refining slag. At this stage the additions of alloy elements, such as nickel, chromium and molybdenum are made (the quantities dependent on the first bath sample analysis) and the contents of the bath again checked to see that the steel conforms with the desired specification, having regard to such losses as may occur during the refining process and such additions as are made in the last stages. Thus two, three, or even four analyses of

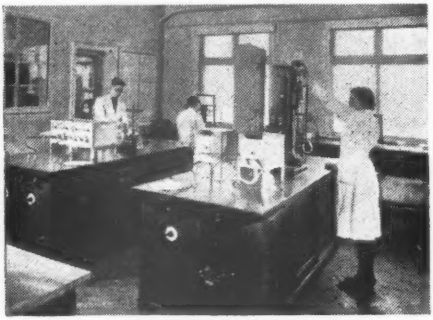


Fig. 9.—Rapid analysis of bath samples.

the steel are made during the steelmaking process on each cast, and the final analysis is made from a sample taken from the ladle after the furnace has been tapped. With a furnace of 3 tons capacity and upwards it is usual to cast at least one test bar with every heat, and on important alloy steels two or three; these, of course, in addition to test bars cast integral with any work which has to meet any of the inspection authorities' requirements. One of these is put through a full heat treatment cycle under laboratory conditions, and others go through the heat treatment cycle with the work from the same cast, which provides a check on the efficiency of the works heat treatment operations.

In steelmaking, also, it is beginning to be appreciated how much temperature control during the various periods of melting influences the efficiency of refinement and deoxidization, and increasing attention is being paid to molten steel pyrometry, and much useful information and helpful controls are now being increasingly used. Absolute

temperature measurement between 1550 and 1700° C has presented quite a few problems in pyrometry, but co-operative effort throughout the steel industry has now enabled suitable instruments to be put in the hands of the steelmaker. In any good foundry, also, research on composition and steelmaking practice is always continuous in a successful endeavour to raise the general standard of cleanliness and physical properties of steels. Indeed, today, the purity and physical properties of high grade electric steel show a marked improvement over practice even five years ago, with a concomitant increase in load carrying capacity.

In addition to the control of raw materials and steelmaking processes, the technical staff of a steel foundry today pays considerable attention to sand controls, both as regards the strength, tensile compression and permeability of the various sand mixtures and the bonding materials which are used, such as colloidal clay and core oils.

Fig. 10.—Sand testing laboratory.

Investigational work is usually proceeding on the design and distribution of feeding heads and runners, and refractory materials (such as furnace and ladle linings, nozzles, sleeves and runners) and refractory facings, washers, and new sands are under test all the time.

Radiology.

Much more attention is being paid today in the steel casting industry to the possibility of radiographic inspection, and there is no doubt that increasing use will be made of radiology, either by X- or gamma-rays, for locating flaws in castings which might otherwise pass unnoticed. Radiology is of the greatest possible help in

building up correct technique for moulding castings, particularly with regard to the efficiency of runners and risers, and is invaluable for the inspection of heavy stressed steel castings where hidden flaws of any dimensions may prove disastrous in service. Although only two or three steel foundries have X-ray plants yet in this country, there is no doubt that the use of radiology for inspection purposes will spread particularly for important castings.,

Investigational work on steel castings is also much helped by the use of magnetic testing for location of surface cracks. The illustration in Figure 12 shows a modern type of magnetic tester used for this purpose. Fine contraction cracks and cracks caused in heat treatment are difficult to detect with the naked eye, particularly after shotblasting which may peen the edges of the crack

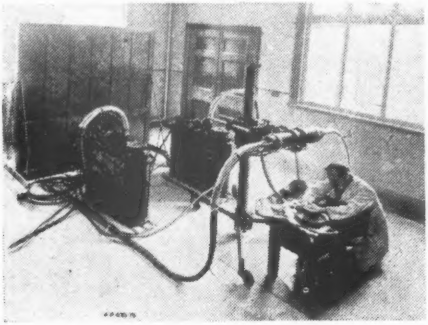


Fig. 11.—300 kV X-ray plant for investigational work on steel castings.

over, but a magnetic tester such as this working, of course, with iron dust suspended in paraffin and sprayed on the casting, forms an easy means of detection.

Conclusions.

In conclusion, the author would emphasise that the production of really sound steel castings is a difficult art and, while such are obviously desirable and necessary, they can only be achieved with the full co-operation of the designer. It should be remembered that, despite the many advances which have been made in the art of founding other metals, cast steel gives a far higher strength for a lower volume of metal than any other cast material, and gives a higher fatigue strength than any other cast material for the same weight. There is no doubt that the field for the use of steel castings has only been scratched.

When alloy steel castings are taken fully into consideration it will be found that they are the most economical material for a large number of engineering parts. Wherever a structure is too complicated to permit of a simple forging or stamping in steel, close investigation will show that the lowest total cost of a part (comparable with equal strength and realibility) can most often be realised by means of a steel casting. Admittedly, a good deal more work remains to be done both in the design and research on steel castings, and it is unfortunate that in many aspects we are not so advanced as some other countries. Steel castings of the type which will be of the

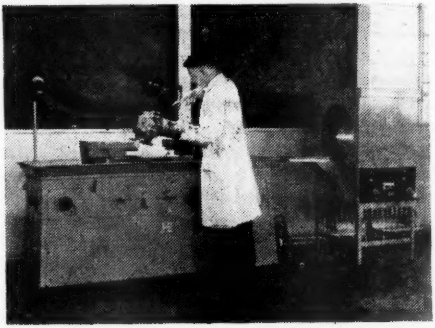


Fig. 12.—Magnetic testing for surface defects.

maximum service to the engineering industry can only be produced by steel foundries whose plant and equipment is modern and installed with a full regard for quality, and whose metallurgical controls are extensive and thorough. While practical experience is, as in any other industry, of the utmost value, it must to-day be backed up by modern equipment and sound and expert metallurgical knowledge, with first class laboratory facilities for control, investigation and research.

Given these things, plus an intelligent and forward outlook on the part of the engineer and designer, there is no doubt we shall in the future achieve engineering productions embodying the use of steel castings which are far in advance of anything we are doing today.

Discussion

MR. BERRIDGE: One of the main themes of the excellent lecture by Mr. Rowe has been the necessity of co-operation between the Drawing Office and the Steel Foundry, with regard to correct designs for producing good castings. Normally, the drawing and pattern is made before the casting price is obtained from one particular foundry, and than perhaps in some cases the job is ultimately given to a different foundry. Instead of discussing this ideal of co-operation and leaving this lecture room with it in our minds, could not some scheme be formulated now? Has Mr. Rowe any suggestions on this view-point?

MR. F. W. ROWE: The soundness of Mr. Berridge's remarks is appreciated. Co-operation between the designer and the steel founder is bound to lead in the long run to a lowering of the cost of sound steel castings, because in some part of the industry and at some time someone has to pay for defective castings. On the other hand, sound designing in co-operation with a steel founder will give the lowest ultimate loss in the steel foundry, and co-operation will also prevent steel castings being used where other forms of construction are preferable and will give the opportunity for the founder to point out obvious economies and suggest where steel castings are more suitable than other types of construction for certain parts. I would also suggest that consumers of steel castings, when they come across defective steel castings in their own shops during machining, should examine these carefully to see whether the fault does really lie with the steel founder or whether the defect is something caused by poor design.

MR. G. D. PICKARD: We get a lot of faulty castings. Sometimes we find blow holes in these and sometimes weld metal, and occasionally we find that there is more weld metal than cast metal. We know that it is difficult to do without this, but one thing that is, is that the weld metal that is put in is very much harder than the cast metal, which leads to difficulties in machining, and I should like to ask Mr. Rowe whether the foundries are not able to remedy this, and make the added metal as easy to machine as the parent metal, which would not be very easy in any case as the parent metal itself is difficult enough sometimes.

Another point is in connection with alterations to the design of castings with a view to reducing the possibility of blow holes. In my business a lot of angle rings are used, and whilst it may be very desirable to do without the square corner inside and make an inner corner radius, it is impossible in view of the duty the ring is to perform, so that it is up to the Steelfounder to apply sufficient

feeding heads to fill that cavity, and the price of steel castings is such to-day that there is no reason why they should not do this. I quite agree that steel castings have not risen in price as much as some other productions, and that present prices are probably justifiable in view of the high cost of installing and operating the elaborate laboratory control which has been illustrated, but I would like the Steelfounders to bear in mind that there will not always be more business than they can cope with. After the war, the Steel Ring would do well to scale their prices down for, if business falls off, as it will, steel castings will otherwise be superseded to a con siderable extent by weldings. One particular case in our own works is that of a large flanged pipe. We used to buy these in considerable numbers before the Ring was formed. The price was put up and I warned our suppliers that they would not stand another rise, but they were not to be deterred and advised another increase. Tools were made to produce this as a welding, since when we have fabricated several hundreds and they will never get that business back again.

Mr. Rowe: As regards the weld metal in steel castings being harder, this I would suggest is largely due to the fault of the founder in doing the welding at the wrong stage. If any welding is required, this should be done before the castings are annealed or heat treated, or the castings re-annealed and reheat treated after welding has been done. If such a procedure is followed there is no reason why the weld metal should be any harder than the parent metal.

It is impossible for the designer always to conform with ideal rules. This the steel founder appreciates, but provided the places where contraction cavities are likely to occur are placed in such a position that the steel founder can get suitable heads on the castings to feed them, sound castings are relatively easy. On the other hand, many of the designs put forward by engineers are such that proper feeding is well nigh impossible and it is these instances where a strong plea is made for reconsideration of design.

As regards welded construction, there are still some designs which are made as steel castings which would be better as welded construction. On the other hand, there are many parts made fabricated which would be more economic as steel castings, and better suited for the duties. Close co-operation between the designer and the maker—whether he be steel founder or fabricator—would result in the most economic and suitable process being applied. On the other hand, the designer should remember that the field is widening for steel castings, particularly with the rise in the use of alloy steels for castings, and with greater attention to design and improved technique in founding, the field would be a good deal wider still. Obviously, of course, there is no permanent gain to the

steel foundry industry to make parts which would be better and more economically made as forgings or as fabricated construction.

MR. CRAWSHAW: Mr. Rowe, I gathered from your address that we have not, in this country, the same facilities as others for the production of steel castings. This was rendered apparent by some British castings we had and some which came from America in recent times. They were the same parts, but the Americans were more easily machined, while the British were none too good.

Why are we lagging behind, and for what reason?

MR. ROWE: I happen to know the particular castings to which Mr. Crawshaw refers. The sole reason in this instance that the American castings were much easier to machine is that the specifications as regards composition and heat treatment of the castings is quite different from the British specification. The American specification calls for 53/58 tons tensile, whereas the British specification calls for 65/72 tons tensile, hence the difference.

MR. H. W. WYATT: Mr. Rowe, at the beginning of his address, expressed a preference for the basic arc type of furnace, but he did not give us any details as to "why and how" he had that opinion. Next to that, he placed the inductive furnace, and, when we consider that the inductive furnace has the powers of uniformly heating metal—and using his own words, "what you put in, you get out"—I think perhaps it would be just as well to explain why he preferred the basic arc furnace.

MR. ROWE: Without, I hope, being too dogmatic, the main reason why I prefer the basic arc electric furnace in front of the induction furnace, as regards quality, is that whilst you get out of the nduction furnace as good metal as you put in, you can get out of the basic arc electric furnace much better metal than is put in. In other words, full refining, both as regards removal of impurities and deoxidation, can be carried to a further degree in a basic arc electric furnace. Steel can be made more pure and more clean in the basic arc electric furnace than in any other steel-making process.

MR. R. W. WHITTLE: Mr. Rowe very kindly extended an invitation to me to visit his plant from which the slides were taken, and I spent a very interesting day in his care going over the whole of the production departments.

After suffering, for rather longer than I care to think, from blow holes and other steel casting defects, I came to the conclusion that uniformity and co-operation were the only channels through which there was a possibility of our availing ourselves of the technique and research which obtains in the plant under review.

During a wireless broadcast one evening recently there was mention of castings assuming the nature of Gruyere cheese, which

reminded me of an incident which occurred about thirty years ago, when a steel casting was being machined which developed a very large blow hole, which one of our fellows said must "weigh quite half a ton."

Reviewing the situation from a Production Engineer's point of view, this question of uniformity and co-operation extends much further than perhaps one imagines. The question of fabrication of parts was not entirely brought about by the difficulty of getting workers in the foundry, but, in a measure, through the difficulty of obtaining continuity of product through strikes and other causes. About twenty-five years ago, when Moulders went on strike, Production Engineers had to do something to help themselves, as a result of which forging and welding received so much attention that this accounts for a large amount of fabrication now going through the various works.

A great deterrent to quality in many industries has been the bug-bear of price and price wars, and at a time when business is bad many people have the idea that it is better to take work at any price than have the foundry standing. This results in much necessary detail being eliminated, reduction of staff, etc., which in turn produces the resultant troubles in bad castings.

I have noticed recently that much is being done in the study of pattern form and alteration as between the Draughtsman, the Founder, and the Production Engineer with considerable benefit both in the design of machine tools and the amount of material to be removed by them. At the present time, one can see in different casts of bombs of large size, different pattern design, which, in some instances, causes the necessity of large amounts of superfluous material to be removed, which, in turn, requires heavy machine tools to accomplish it.

The Production Engineer who travels from one factory to another at the present time notices at what an amazing rate progress is being made in change of design and the specialised machine tool operations which are being adapted to mass production. In the large shadow and Ministry factories which are now being equipped throughout the country the engineer finds his machine tool dream coming true, and it will be difficult for many post-war engineers to keep pace with their contemporaries if they have been unfortunate in availing themselves of the opportunities at present afforded.

I hope the Institution of Production Engineers will take every opportunity during the coming months for their members to visit various factories in the districts in which branches are operating, so that the members may be fully acquainted with the plant being operated by their friends.

MR. ROWE: I must thank Mr. Whittle very much for the most helpful suggestions and advice he has given us all. In Mr. Whittle,

we have a most experienced engineer, and all of us who know him, and realise the vast fund of experience and knowledge which he has, appreciate the sound type of advice he has given us today.

MR. T. N. SMITH: On the subject of co-operation, I would just like to have one word and this is it. Before the war, the steel foundries used to have representatives who came round to see us and they used to see the patternmaker and designer and discuss any problems which might have arisen. Since the war, owing to the lack of labour and travelling facilities, we no longer see that representative and we as a firm of steel casting users find that we are at a disadvantage. We admit that our designers and patternmakers are still making mistakes from the point of view of the steel foundry and there is no doubt these will be lessened by closer co-operation. Do you not think it a good plan to consider sending a technical man round from the steel founders to see the users sometimes?

MR. ROWE: The ignorance of the designer and pattern maker is to a large extent the steel founder's own fault. The steel founder is generally a relatively inarticulate person and very often, he would rather attempt to cope with these nearly impossible designs than raise a complaint against the designer, but if the designer would consider the liquid contraction which has to be catered for in any steel casting, he would realise that he is setting problems that are almost impossible, and he ought to realise when grumbling about high price how much a steel founder's costs are enhanced by trying to cater for these almost impossible demands of the designer.

CAPTAIN L. J. SARGEANT: I saw a little while ago a leaflet got out by F. A. Hughes & Co., which gave very useful points for designers to watch when they were using Elektron metal. I obtained copies of this and distributed them to my chief draughtsmen and principal people. After listening to this most interesting lecture, I feel that steel founders might get out a similar sheet emphasising the points which Mr. Rowe has brought out in the lecture today and illustrate these points in that simple, clear and straight-forward way, and distribute these to their customers. I am sure they would find them useful.

I should like to add a word as one who has been at the customers end with regard to steel castings for some 35 years—I have proved to my own satisfaction that it does not often pay to buy steel castings at the cheapest price.

I remember many years ago, when I was on the shop floor, protesting to the supply officer about some steel castings which he had bought, basing my protest in the first place on the amount of welding that had to be done. His reply was that in fixing up the contract he had allowed 5/- per cwt. for welding and still the supplier of these castings was cheaper than a competitive firm who had also

been invited to tender. I tried to point out to him that 5/- a cwt. even if it paid for the welding, would not pay for the cost of a disturbed organisation, which it was almost impossible to assess.

I would from my own experience stress the need for fair and reasonable dealings of steel founders by the buyers when conditions favour the buyers. I know of cases during the depression where any buyer who had a good steel order to place could go to a steel founder and demand a 15 per cent or 20 per cent cut below the market price, which the wretched producer found very hard to refuse knowing of his half empty foundry behind and the overheads piling up. Where I had anything to do with it, I always refused to adopt these tactics and I have found since that the good will so created was worth a great deal more than the saving when the conditions changed round, as they do, and always will do, periodically. I mention this because it all helps to build up that atmosphere of co-operation between the founder and user which is so necessary if the best over-all result is to be obtained, and I must say I have always had a great admiration for the way the steel founder tackles his job and the help he is prepared to give when difficulties arise if he is only asked and treated as a human being.

MR. ROWE: I most heartily endorse Captain Sarjeant's words referring to a code for designers. I think that something ought to be done, and I will use his suggestion in the right quarters.

I was very pleased to have his remarks on the apparent savings in cost by buying steel castings cheaply. These savings are only apparent. A few pence or shillings saved in cost per cwt. can easily be lost in delays in the production line; costs which are very difficult to assess.

As a steel founder, I was correspondingly grateful for Captain Sarjeant's obvious sympathy with our position when dealing with certain types of buyers. Unfortunately, after the last war, the steel founding industry was left with a capacity far higher than the demand, which led to considerable price cutting with deterioration in quality.

MR. R. FOSTER: In regard to co-operation between founders and production engineers, I think the pattern maker should not be forgotten. A very important question is that of drawing. Generally, engineers send into the pattern shop a drawing of the finished machined article showing by symbols parts that are to be machined. A pattern maker probably thinking in terms of iron, although working on a double contraction rule, can, by adding the little extra machining on the pattern, probably in an inaccessible position for headers, be responsible for a change in section at an important part of the casting, *i.e.*, the machined part. Therefore, if the engineer, while designing for steel castings and keeping the section of casting as uniform as possible, must do so as a steel casting and not as a

finished machined article. If a pattern drawing was issued showing the article as cast, not machined, I think you would find that you would have less faulty castings sent back. Little things like this would help in giving a better job.

Mr. Rowe: I quite agree with what Mr. Foster has said, and it has struck a chord in my mind on a similar position, which I rather hesitate to mention at a gathering of engineers. It is this; I can never understand why engineering firms should think it an economy to make its own patterns for steel castings.

The difficulties to the steel founder are always enhanced by this, as an engineer's own pattern shop does not know the requirements of the steel founder. If the steel founder had an opportunity of making his own patterns, economy both in manufacture and subsequent machining would generally result, and the steel founder would also have a better chance of producing sound castings. The savings in an engineering shop making its own pattern are infinitesimal and not worth the trouble and risk involved to the steel founder. Any good steel foundry would prefer to make its own patterns for any particular job, as it realises that it often has to adopt uneconomical methods of moulding and pouring and take greater risks of unsound castings due to the patterns having been made by the engineer without full appreciation of the steel founder's needs.

FIRST REPORT OF THE WELDING SUB-COMMITTEE OF THE INSTITUTION OF PRODUCTION ENGINEERS

MANY months ago the Technical and Publications Committee recognised the value of welding as a production tool. It was therefore decided to set up a Welding Sub-committee, and it was my pleasure, as Chairman of the Technical and Publications Committee at that time, to initiate this Sub-committee under the Chairmanship of Mr. J. T. Knight, A.M.I.P.E.

The first task confronting the Committee was to decide, within the vast field of welding (embodying as it does so many variations, what should be the correct priority governing its activities.

It was decided, and I think it was a very wise choice, that the inspection of Welding was of primary importance. Members felt that the value of a process, and its acceptance by Designers and Production Engineers, varies in direct relationship to the manner in which the standard of performance can be measured. In the case of welding, it has long been a disadvantage that these standards of performance are not capable of exact measurement in quite the same manner as many other processes of production. So much still depends on the abilty of the individual welder, and, generally speaking, the more the human element has to be relied upon in a production process, the more difficult it becomes to control. The Inspection of Welds therefore was accepted by the Committee as being its guiding principle.

Since that date the Sub-committee has consistently followed this policy and decided to commence its investigations into the quality control of resistance spot welding, which is probably more widely used than most other types of welding. It is now, after many months, in a position to issue its first report, which will be found below.

I would like to congratulate the Sub-committee on this initial effort, and I recommend it very carefully to the attention of all who utilise the process of spot welding in their own companies.

W. PUCKEY (*Member*)

THE INSPECTION OF WELDING

(I) *Resistance Spot Welding*

THE Welding Sub-Committee has been set up to consider problems in the use of welding which interest the production engineer.

With the extension of the use of welding for mass produced articles, the development of the methods of inspection which will ensure the quality of the product without slowing down production is a matter of immediate importance, and it was agreed that this Committee should apply itself, in the first instance, to the inspection of spot welding. The memorandum on the Inspection and Control of Quality of Spot Welds in Mild Steel, issued by the Advisory Service on Welding of the Ministry of Supply, is the first authoritative statement on this subject and has been taken as a basis for the work of the Committee.

It was considered by the Committee that the figures given for the allowable increase in the diameter of the electrode tip before changing were unduly restricted, and that the subject warranted experimental investigation.

By the courtesy of The Pressed Steel Company Ltd., Oxford, Mr. W. S. Simmie has carried out an extended series of investigations which forms the subject of this first report of the Welding Sub-Committee.

Scope of Experimental Work.

It was decided to investigate the relationship between the diameter and the shear strength with a view to determining the safe limit of increase in tip diameter. The work also included an investigation on the performance of three types of electrode material.

By far the greater proportion of work being spot welded at present is of light gauge mild steel, up to a thickness of $^1/_{16}$ in. The present investigation was therefore confined to 20 S.W.G. autobody sheet, which was considered to be the material in most common use.

Equipment Employed.

The welding machine employed was part of the experimental equipment installed in the welding laboratory of The Pressed Steel Company Ltd., The relevant features of the machine are :—

Pressure. Air operated direct-acting pressure head, permitting a maximum pressure between electrodes of 1,000 lb.

Control. The control of the welding current was by means of an ignitron contactor in conjunction with a mechanical type of timing control, permitting welding times of from five cycles ($^1/_{10}$ of a second) up to five seconds. In addition the "forging" time, or time of the dwell of the electrode on the work after the welding current has ceased and with full pressure still applied, was controlled by a similar device.

Electrodes. In making these tests advantage was taken of information obtained from America where it has been established that a flat circular contact area as presented by a truncated cone is generally quite suitable for this gauge of mild steel. The electrodes were made from $\frac{3}{4}$ in. diameter bar and the form used is illustrated in Fig. 1. For this investigation electrode tips were carefully machined and dimensions checked before use. New electrodes were introduced for each test.

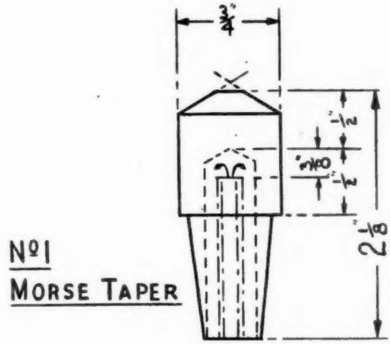


Fig. 1.—Details of Welding Electrode.

Size of Electrode Tip.

Having regard to the gauge of material involved, it was decided to confine the initial sizes of tips to $\frac{1}{4}$ in. and $^3/_{16}$ in. The majority of the work was carried out with the $\frac{1}{4}$ in. size.

Pressure.

The pressure applied to the electrodes was based on pressure intensities of 7/10,000 lb. per square inch of initial tip area. Although a higher pressure intensity is sometimes advocated it was limited to the above range in the present investigation due to considerations of lower arm deflection. It is also likely that similar difficulty would arise on most production machines of capacity suitable for this work.

Time.

A weld time of 10 cycles ($^1/_5$th second) was selected for all tests after preliminary investigations had been carried out to determine the maximum shear strength value which could be obtained.

Current.

As the current value obviously must have considerable influence on the rate of increase of size of electrode tip, it was decided to adopt values of current which would represent as wide a range as considered likely to be employed under production conditions with the above timing. For the $\frac{1}{4}$ in. diameter tip, the secondary current values were 9,220 amps, 8,200 amps, and 7,620 amps. For the $^3/_{16}$ in. diameter tip the current values used were 7,620 and 7,020 amps.

Speed of Operation.

It was found most suitable to weld at a rate of 40 spots per minute, and this was employed throughout.

Cooling Water to Electrodes.

Cooling water was supplied from the mains at a rate of one gallon per minute to each electrode.

Recording of Results.

As the most important property of a weld is its strength, an endeavour was made to employ this factor as the common basis for comparison of all the experimental welds made. Accordingly at given intervals throughout each series of tests, single spot weld shear specimens were prepared for testing in a tensile testing machine and the average strengths of three consecutive specimens are recorded in the tabulated results.

Measurement of Tip Diameter, Contact Area, and Impression Diameter.

Before proceeding with this work consideration was given to the methods available for accurately measuring the tip diameter

and the contact area of the tip. Two instruments were used for measuring the tip diameter—namely—a Brinell microscope graduated in tenths of a millimeter and a projection microscope on which the tip profile was projected. It was found that the Brinell microscope gave results comparable with the projection microscope and it was considered more suitable as the diameter could be measured by moving the arm extension which carries the electrode holder without disturbing the fit of the electrode in its tapered seating

The method adopted for measuring the contact area was similar to that used by American investigators. A sandwich consisting of a strip of 1 mm. squared paper, a strip of carbon paper (with the carbon face towards the squared paper) enclosed in a sheet of copper foil. The electrodes were brought together with the full welding pressure applied to them and the contact area was recorded on the squared paper. This area was estimated by a careful study of the impression under a magnifying glass. For purposes of graphical comparison the contact area, as measured, has been converted to a circular area, the diameter of which is used to enable a linear relationship to be obtained with the tip diameter and impression diameter.

Description of Work.

The following items were investigated :—

(a) Form of electrode tip.

(b) Comparison of electrode materials.

(c) Measurement of electrode tip wear. In this series of tests variations in welding current, welding pressure, and initial electrode tip diameter were considered.

(a) *Form of Electrode Tip.*

Preliminary work indicated that the rate of increase of the tip area was very much influenced by the angle sub-tended by the conical portion of the electrode tip. Therefore, a series of experiments were made using included angles of 70°, 90° and 120°. As a result of these experiments it was proved that there was a very definite advantage in using the tip included angle of 120° ; for example, an increase in tip diameter from 0.25 to 0.29 in. produced 800 welds with 70° included angle, 1,120 welds with 90° included angle, 5,000 with 120° included angle. Consideration must also be given to any interference with the vision of the operator when positioning the work between the electrode tips, and it would appear that any increase in the included angle above 120° might cause difficulty in this respect. (These test are recorded in Tables

1, 2, and 3, and illustrated in graph form in Fig. II). As a result the remaining tests were carried out with a tip included angle of 120°.

(b) *Comparison of Electrode Materials.*

In order to obtain data on the effect of various copper alloys as tip material, those commonly used materials were chosen as being

FIG. II FORM OF ELECTRODE TIP

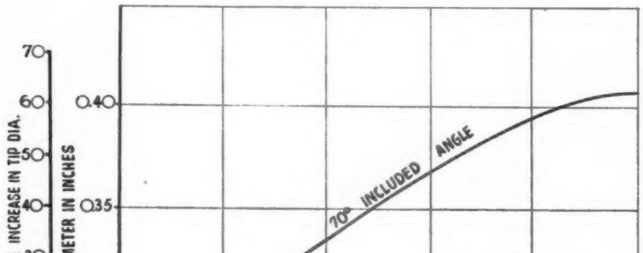


Fig. II.—The effect of varying the included angle. (¼" dia. electrode).

representative of those most widely employed. These are designated for reference purposes as "A," "B" and "C." The approximate composition and hardness of these alloys were as follows :—

"A" 0.9% Cadmium Copper—Vickers Hardness No. 110.

"B" 0.6% Chromium, 0.20% Silicon Copper—Vickers Hardness No. 145.

"C" 1.2% Cadmium Copper—Vickers Hardness No. 145.

Tests were carried out using a constant welding pressure of 10,000 lb. per square inch, and welding currents of 9,220 and 7,620 amps. Test results for Material "A" are given in Tables 4 and 5; for Material "B" in Tables 6 and 7; and for Material "C" in Tables 8 and 9. The results are represented in graph form in Fig. III and IIIa.

FIG III COMPARISON OF ELECTRODE MATERIALS (9220 AMPS.)

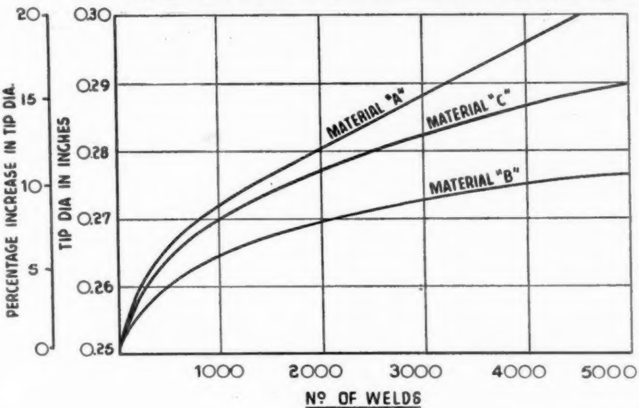


FIG IIIA COMPARISON OF ELECTRODE MATERIALS (7620 AMPS)

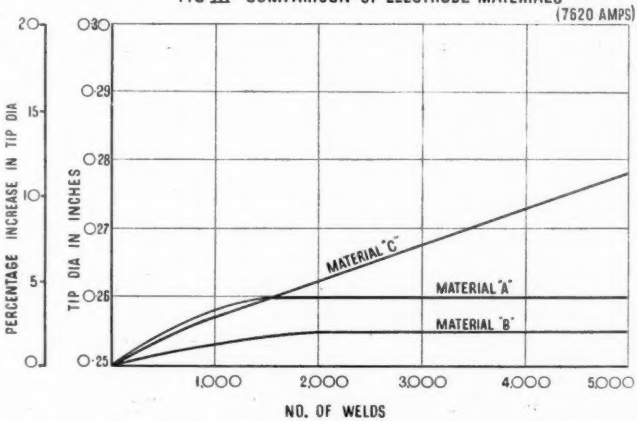


Fig. III and IIIa.—Comparison of electrode materials. (Included angle 120°).

Referring to Fig. III and IIIa, it can be seen that Material "B" wears better than the cadmium alloys. A further comparative test was carried out on Materials "A" and "B" using an initial tip diameter of $^3/_{16}$ in., and a welding current of 7,260 amps. The results are given in Tables 10 and 11, and illustrated in graph

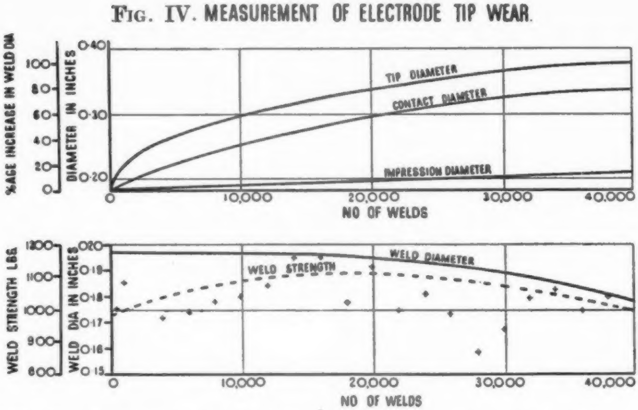


Fig. IV.—Comparative test on electrode materials "A" and "B." (Included angle 120°).

form in Fig. IV. It should be noted that in these tests the choice of electrode material does not to any extent affect the shear strength of the weld. This is to be expected with materials all having the order of conductivity.

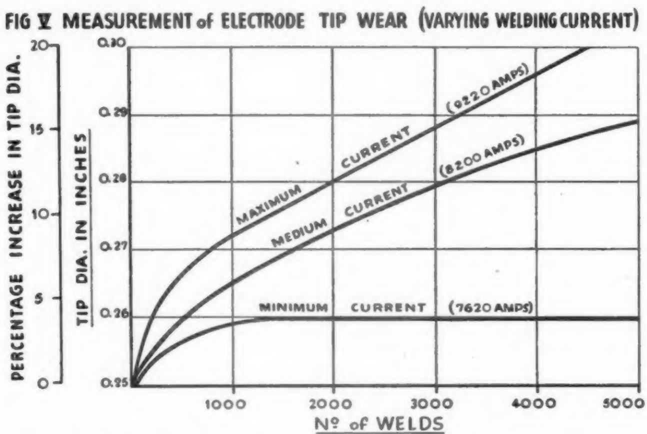


Fig. V.—The effect of varying the welding current. (included angle 120°, ¼" dia. electrode).

(c) *Measurement of Electrode Tip Wear.*

(i) *The effect of varying welding current with ¼ in. dia. tips.* Tests were carried out using a constant welding pressure and welding currents of 9,220, 8,200 and 7,620 amps. The results are given in Tables 12, 13 and 14, and illustrated in graph form in Fig. V. An increase in the welding current results in increased electrode tip wear. The shear strength value of the weld is also increased by using higher welding currents.

(ii) *The effect of varying the welding current with $^3/_{16}$ in. dia. tips.* Further tests were carried out in which the electrode tip diameter was reduced from ¼ to $^3/_{16}$ in. Welding currents of 7,620 and 7,020 amps. were selected, one being the maximum welding current which could be used without over-heating the weld surface, and the other a medium current which would give a satisfactory weld shear strength value. The results are given in the Tables 15 and 16, and illustrated in graph form in Fig. VI. As in the previous test the wear on the electrode tip was increased by increasing the welding current.

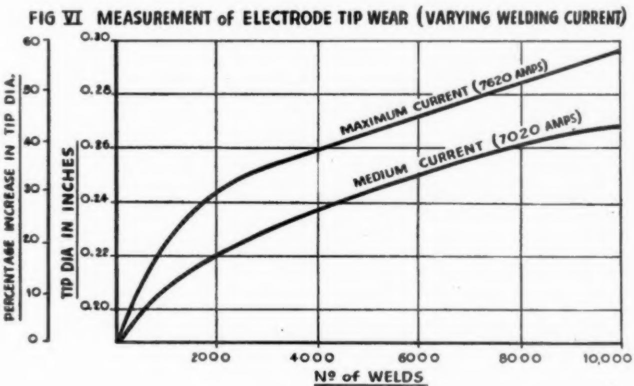


Fig. VI.—The effect of varying the welding current. (Included angle 120°, $^3/_{16}$ dia. electrode).

(iii) *The effect of varying the electrode tip diameter.* A comparison of the rate of increase of tip diameter for the two sizes of electrode tips employed can be obtained from Fig. VII where percentage increase is plotted against the number of welds. The high current values for each size of tip were used and it will be seen that the rate of increase is initially very much greater with the smaller tip size.

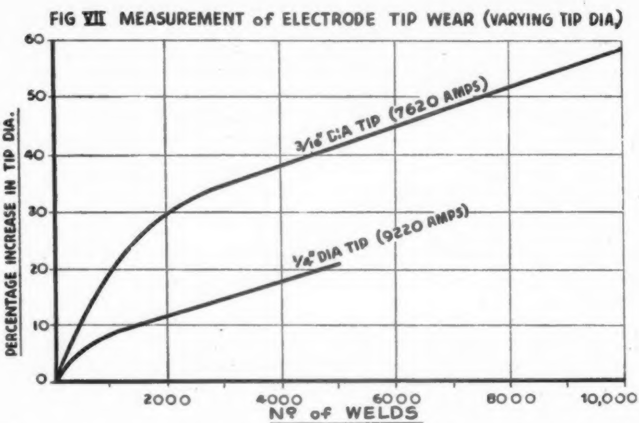


Fig. VII.—Comparison of ¼" and $\frac{3}{16}$" dia. tips. Material "A." (Included angle 120°).

(iv) *The effect of varying the welding pressure.* Tests were carried out using welding pressures of 10,000 and 7,500 lb. per square inch of initial tip area, and a welding current of 9,220 amps. The results are given in Tables 17 and 18, and these are represented in graph form in Fig. VIII. It can be seen that increased electrode pressure

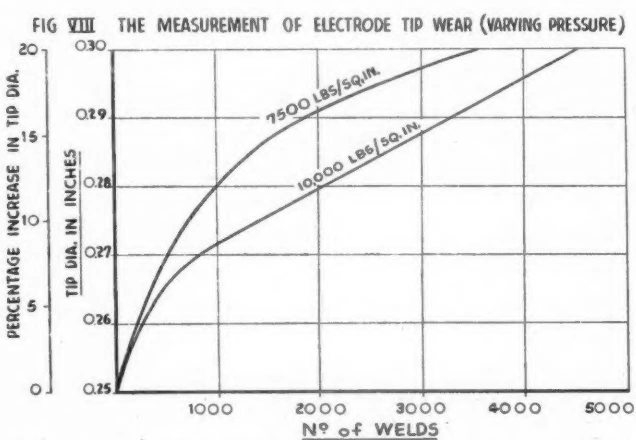


Fig. VIII. The effect of varying welding pressure. (Included angle 120°).

appears to reduce slightly the wear on the electrode tips. The use of a higher pressure reduces somewhat the resistance between the electrode tips and the sheet, and also the sheet to sheet resistance, resulting in a decreased generation of heat at these points during passage of welding current. This brings about a slight reduction in the shear strength values of welds obtained, and also explains the reduction in wear of the electrode tips.

Consideration of the results so far obtained made it clear that the weld strength did not fall off at all proportionately with the considerable increases in the electrode tip diameter as measured. Accordingly, a further series of test measurements were made of tip diameter, contact area, and impression diameter, with a view to deciding which factor offered the best means of inspection control of the weld strength. The results are recorded in Tables 10 and 11 for two electrode materials " A " and " B " and this series was extended to 40,000 welds in the anticipation that eventually the shear strength of the welds would show a marked reduction and inconsistency.

No reduction in weld strength occurred with these extended tests, and the reason is apparent from a study of the results which have been plotted for Table 10 in Figure IX. It will be seen that the figures for weld diameter and shear strength and impression diameter remain appreciably constant throughout.

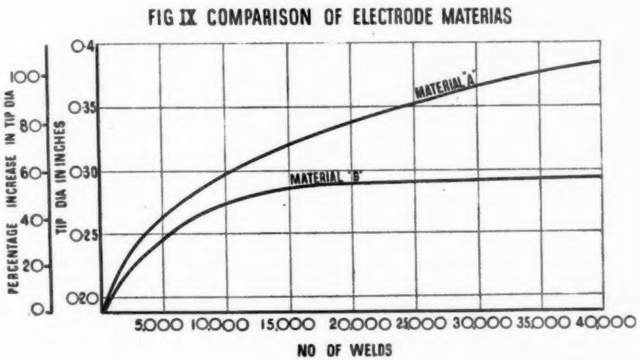


Fig. IX.

The over-all tip diameter is therefore not a true indication of the contact area when the weld time is short. If, however, longer weld times are employed it is likely that the impression of the tip into the sheet surface would become greater, and that the area in

contact would approach the over-all tip area as the timing is increased.

The contact diameter, as measured by the method described, apparently gives readings approaching the measured tip diameter, and as the tip diameter is more easily obtained in practice it does not appear that the measurement of contact area is a practical means of inspection control.

From the above it would seem that the most reliable control would be obtained by measurement of the impression diameter, but it was found that the measurements, as taken by different persons, were likely to vary widely due to difficulty in deciding which is the actual boundary of the impression. The impression also tends to become indistinct, as is evidenced by actual photographs of welds taken at different stages of these test series. (See photographs reproduced at the end of this report).

In spite of the uniformity of weld strength, as shown in Fig. IX, it is not suggested that this number of welds could be permitted in production before changing the electrodes due to the rather poor surface appearance which occurs after about 10,000 welds with Material " A," or 22,000 welds with Material " B." As the measured increase in impression diameter for these number of welds is so small, it would be quite impossible to employ this factor as a means of control.

Conclusions.

From the above experimental work carried out on the spot welding of 20 S.W.G. Clean Mild Steel Sheet, the following conclusions can be drawn :—

(1) A truncated cone having 120° included angle can be recommended as a tip contour from considerations of tip life and suitability for production.

(2) The only feasible method of control of electrode tip size is by measurement of the over-all tip diameter and examination of the appearance of the weld impression.

(3) Although an increase up to 103% in the tip diameter was recorded without severe falling off in weld strength or consistency, it appears necessary to limit the number of welds made under the stated conditions to the point at which surface appearance commences to deteriorate rapidly. (NOTE : With conditions of weld time and current different from those used in this investigation it is possible that weld strength will fall off before the surface appearance

deteriorates). It is therefore necessary to point out that the permissible tip diameter should not exceed 30% for $\frac{1}{4}$ in. tips and 50% for $^3/_{16}$ tips.

(4) Choice of electrode material can affect very considerably the number of welds that can be performed before re-machining is necessary. For $^3/_{16}$ in. diameter tips the use of Material "B" appears to permit twice the number of welds that can be made with Material "A" for equal tip increase and surface appearance.

(5). In view of the probable effect of increased weld time on the permissible increase in tip diameter it is clear that there is scope for further research work along these lines before full production data can be provided.

(6) Careful attention should be paid to the water cooling of the electrode tips, and a flow of one gallon per minute to each electrode appears adequate for conditions as employed in this investigation.

RECOMMENDATIONS

Arising out of the discussions of the Welding Sub-committee the following recommendations are made :—

1. Electrode shanks to conform to B.S.S.
2. Rectification of electrode tips to be made only by machining. The procedure suggested is that when the tip diameter reaches the maximum permissible, it should be replaced by a new one or rectified tip from store. All electrode tips should bear an approved mark, stamped upon the conical face, and so arranged that rectification removes it. Submission to the Inspection Authority for re-marking after rectification will ensure rectification by machining only.
3. The use of a simple plate gauge as shown below for checking tip diameter growth.

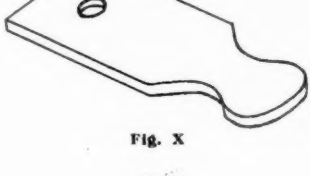
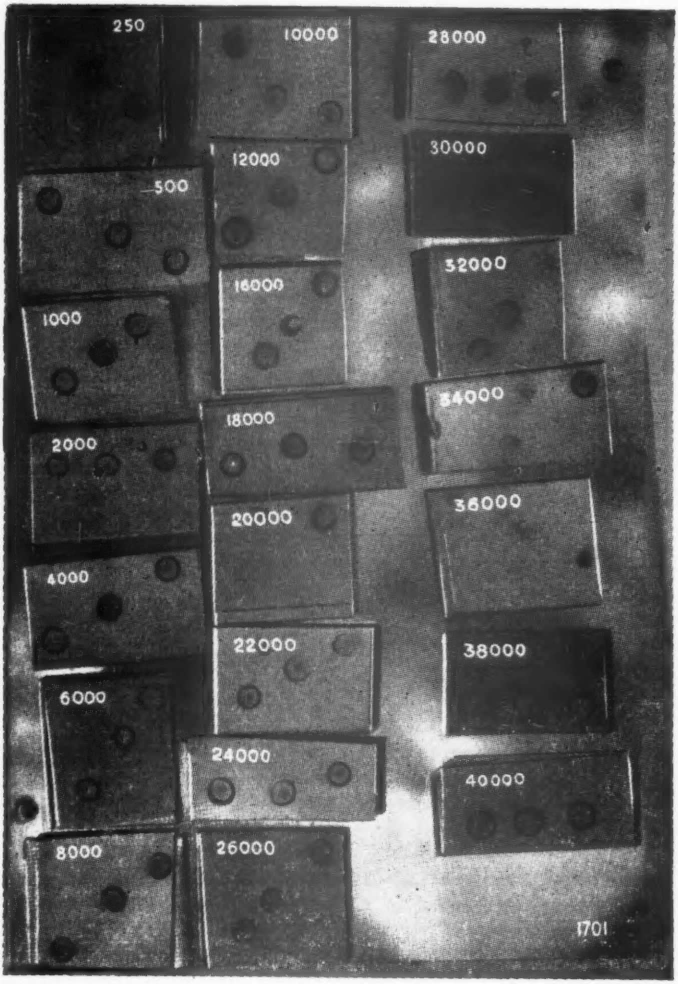


Fig. X


250
10000
28000
12000
30000
500
16000
32000
1000
18000
34000
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40000
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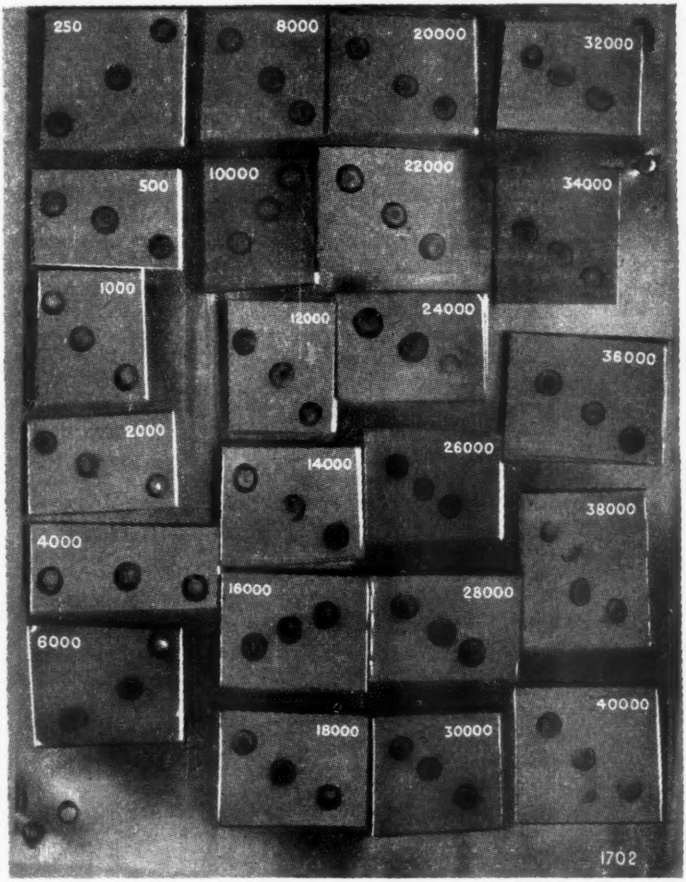
1701


250
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36000
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38000
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40000
1702

4. Routine tests as laid down in Ministry of Supply Memorandum, No. 8, pages 4 and 5, using test coupon form as shown in Fig. XI below.

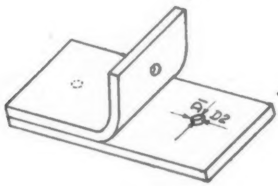

Fig. XI.

TABLE 1.

Form of Electrode Tip.

$\frac{1}{4}$ in. diameter tip. Included angle 70°.

Welding Current : 8,200 amps. Speed of Welding : 40 weld/min.
Electrode Pressure : 10,000 lb./sq. in. Welding Time : 10 cycles.
Water Cooling : 1 gal./min./electrode.

No. of Welds	*Tip Dia.*	*Tip Area*	*Breaking load of Spot Welds in lbs. (1 in. overlap)*
0	.25″	.0491 sq.in.	1180
500	.297″	.0695 ,,	1240
1000	.297″	.0695 ,,	1140
1500	.3125″	.0767 ,,	1150
2000	.344″	.0928 ,,	1240
2500	.344″	.0928 ,,	1120
3000	.375″	.1104 ,,	1320
3500	.375″	.1104 ,,	1130
4000	.406″	.1296 ,,	1196
4500	.406″	.1296 ,,	1190
5000	.406″	.1296 ,,	1130

TABLE 2. (FIG II.)

Form of Electrode Tip.

$\frac{1}{4}$ **in.** diameter tip. Included angle 90°

Welding current : 8,200 amps. Speed of Welding : 40 welds/min.
Electrode Pressure : 10,000 lb./sq. in. Welding Time : 10 cycles.
Water Cooling : 1 gal./min./electrode.

No. of Welds	*Contact Area*	*Tip Dia.*	*Tip Area*	*Breaking load of Spot Welds in lbs.* (1″ *overlap*)
0	.0491 sq.in.	.25″	.0491 sq.in.	1190
250	.040 ,,	.26″	.0533 ,,	1125
500	.0413 ,,	.27″	.0574 ,,	1090
1000	.0464 ,,	.285″	.0639 ,,	1200
1500	.0475 ,,	.295″	.0684 ,,	1190
2000	.050 ,,	.300″	.0706 ,,	1160
2500	.050 ,,	.300″	.0706 ,,	1160
3000	.055 ,,	.31″	.0755 ,,	1180
3500	.055 ,,	.31″	.0755 ,,	1140
4000	.055 ,,	.31″	.0755 ,,	1170
4500	.055 ,,	.31″	.0755 ,,	1170
5000	.055 ,,	.31″	.0755 ,,	1120

TABLE 3. (FIG. II.)

Form of Electrode Tip.

$\frac{1}{4}$ in. Diameter tip. Included angle 120°

Welding Current : 8,200 amps. Speed of Welding : 40 welds/min.
Electrode Pressure : 10,000 lb./sq.in. Welding Time : 10 cycles.
Water Cooling : 1 gal./min./electrode.

No. of Welds	*Contact Area*	*Tip Dia.*	*Tip Area*	*Breaking load of Spot Welds in lbs.* (1″ *overlap*)
0	.04 sq. in.	.25″	.0491 sq.in.	1140
250	.0375 ,,	.26″	.0533 ,,	1150
500	.0375 ,,	.27″	.0574 ,,	1040
1000	.0375 ,,	.27″	.0574 ,,	1140
1500	.0375 ,,	.27″	.0574 ,,	1120
2000	.0375 ,,	.27″	.0574 ,,	1220
2500	.0375 ,,	.27″	.0574 ,,	1310
3000	.0425 ,,	.28″	.0614 ,,	1220
3500	.045 ,,	.285″	.0639 ,,	1150
4000	.045 ,,	.285″	.0639 ,,	1130
4500	.045 ,,	.285″	.0639 ,,	1210
5000	.0475 ,,	.29″	.0660 ,,	1150

TABLE 4. (FIG. III.)

Comparison of Electrode Materials. Material "A."

¼ in. Diameter tip. Included Angle 120°

Welding current : 9,220 amps. Speed of Welding : 40 welds/min.
Electrode pressure : 10,000 lb./sq.in. Welding time : 10 cycles.
Water cooling : 1 gal./min./electrode.

No. of Welds	*Contact Area*	*Tip Dia.*	*Tip Area*	*Weld strength/spot taken from average of three welds. (1″ overlap)*
0	.0400 sq.in.	.25″	.0491 sq.in.	1100 lb
250	.0400 ,,	.26″	.0533 ,,	1320 ,,
500	.0425 ,,	.27″	.0574 ,,	1150 ,,
1000	.0425 ,,	.27″	.0574 ,,	1270 ,,
1500	.0450 ,,	.28″	.0614 ,,	1210 ,,
2000	.0450 ,,	.28″	.0614 ,,	1310 ,,
2500	.0450 ,,	.28″	.0614 ,,	1260 ,,
3000	.0475 ,,	.29″	.0660 ,,	1320 ,,
3500	0500 ,,	.29″	.0660 ,,	1220 ,,
4000	.0525 ,,	.30″	.0706 ,,	1180 ,,
4500	.0525 ,,	.30″	.0706 ,,	1300 ,,
5000	.0550 ,,	.30″	.0706 ,,	1320 ,,

TABLE 5. (FIG. IIIa.)

Comparison of Electrode Materials. Material "A."

¼ in. Diameter tip. Included Angle 120°.

Welding current : 7,620 amps. Speed of Welding : 40 welds/min.
Electrode pressure : 10,000 lb./sq.in. Welding time : 10 cycles.
Water cooling : 1 gal./min../electrode.

No. of Welds	*Contact Area*	*Tip Dia.*	*Tip Area*	*Weld strength/spot taken from average of three welds. (1″ overlap)*
0	.0400 sq.in.	.25″	.0491 sq.in.	1170 lb.
250	.0400 ,,	.25″	.04909 ,,	1000 ,,
500	.0400 ,,	.25″	.04909 ,,	1090 ,,
1000	.0425 ,,	.26″	.0533 ,,	1200 ,,
1500	.0425 ,,	.26″	.0533 ,,	1080 ,,
2000	.0425 ,,	.26″	.0533 ,,	1090 ,,
2500	.0425 ,,	.26″	.0533 ,,	1010 ,,
3000	.0425 ,,	.26″	.0533 ,,	1060 ,,
3500	.0425 ,,	.26″	.0533 ,,	950 ,,
4000	.0450 ,,	.26″	.0533 ,,	1000 ,,
4500	.0450 ,,	.26″	.0533 ,,	1050 ,,
5000	.0450 ,,	.26″	.0533 ,,	1030 ,,

TABLE 6. (FIG. III.)

Comparison of Electrode Materials. Material "B."

¼″ Diameter tip. Included Angle 120°

Welding current : 9,220 amps. Speed of welding : 40 welds/min.
Electrode pressure : 10,000 lb./sq.in. Welding time : 10 cycles.
Water cooling : 1 gal./min./electrode.

No. of Welds	*Contact Area*	*Tip Dia.*	*Tip Area*	*Weld strength/spot taken from average of three welds.* (1″ *overlap*)
0	.0375 sq.in.	.25″	.0491 sq.in.	1190 lb.
250	.0375 ,,	.26″	.0533 ,,	1190 ,,
500	.0375 ,,	.26″	.0533 ,,	1370 ,,
1000	.0375 ,,	.27″	.0574 ,,	1280 ,,
1500	.0400 ,,	.27″	.0574 ,,	1280 ,,
2000	.0425 ,,	.27″	.0574 ,,	1120 ,,
2500	.0425 ,,	.27″	.0574 ,,	1280 ,,
3000	.0425 ,,	.27″	.0574 ,,	1220 ,,
3500	.0425 ,,	.275″	.0594 ,,	1120 ,,
4000	.0425 ,,	.275″	.0594 ,,	1280 ,,
4500	.0425 ,,	.275″	.0594 ,,	1090 ,,
5000	.0425 ,,	.28″	.0594 ,,	1100 ,,

TABLE 7. (FIG IIIa.)

Comparison of Electrode Materials. Material "B."

¼″ Diameter tip. Included Angle 120°.

Welding current : 7,620 amps. Speed of welding : 40 welds/min.
Electrode pressure : 10,000 lb./sq.in. Welding time : 10 cycles.
Water cooling : 1 gal./min./electrode.

No. of Welds	*Contact Area*	*Tip Dia.*	*Tip Area*	*Weld strength/spot taken from average of three welds.* (1″ *overlap*)
0	.04 sq.in.	.25″	.0491 sq.in.	1080 lb.
250	.04 ,,	.25″	.0491 ,,	965 ,,
500	.04 ,,	.25″	.0491 ,,	915 ,,
1000	.04 ,,	.25″	.0491 ,,	1090 ,,
1500	.04 ,,	.255″	.0511 ,,	970 ,,
2000	.0425 ,,	.255″	.0511 ,,	980 ,,
2500	.0425 ,,	.255″	.0511 ,,	1025 ,,
3000	.0425 ,,	.255″	.0511 ,,	980 ,,
3500	.0450 ,,	.255″	.0511 ,,	985 ,,
4000	.0450 ,,	.255″	.0511 ,,	1065 ,,
4500	.0450 ,,	.255″	.0511 ,,	1086 ,,
5000	.0450 ,,	.255″	.0511 ,,	1030 ,,

TABLE 8. (FIG. III.)

Comparison of Electrode Materials. **Material "C."**

¼″ Diameter tip. Included Angle 120°.

Welding current : 9,220 amps. Speed of welding : 40 welds/min.
Electrode pressure : 10.000 lb./sq.in. Welding time : 10 cycles.
Water cooling : 1 gal./min./electrode.

No. of Welds	*Contact Area*	*Tip Dia.*	*Tip Area*	*Weld strength/spot taken from average of three welds.* **(1″ *overlap*)**
0	.0400 sq.in.	.25″	.0491 sq.in.	1180 lb.
250	.0425 ,,	.26″	.0533 ,,	1190 ,,
500	.0425 ,,	.265″	.0552 ,,	1190 ,,
1000	.0425 ,,	.27″	.0574 ,,	1040 ,,
1500	.0425 ,,	.275″	.0594 ,,	1180 ,,
2000	.0425 ,,	.28″	.0614 ,,	1230 ,,
2500	.0450 ,,	.28″	.0614 ,,	1070 ,,
3000	.0450 ,,	.285″	.0639 ,,	1110 ,,
3500	.0450 ,,	.285″	.0639 ,,	1120 ,,
4000	.0450 ,,	.285″	.0639 ,,	1020 ,,
4500	.0475 ,,	.29″	.0660 ,,	1120 ,,
5000	.0475 ,,	.29″	.0660 ,,	1150 ,,

TABLE 9. (FIG. IIIa.)

Comparison of Electrode Materials. **Material "C."**

¼″ Diameter tip. Included Angle 120°

Welding current : 7,620 amps. Speed of welding : 40 welds/min.
Electrode pressure : 10,000 lb./sq.in. Welding time : 10 cycles.
Water Cooling : 1 gal./min./electrode.

No. of Welds	*Contact Area*	*Tip Dia.*	*Tip Area*	*Weld strength/spot taken from average of three welds.* **(1″ *overlap*)**
0	.04 sq.in.	.25″	.0491 sq.in.	1010 lb.
250	.04 ,,	.25″	.0491 ,,	1130 ,,
500	.04 ,,	.25″	.0491 ,,	1130 ,,
1000	.0425 ,,	.26″	.0533 ,,	1080 ,,
1500	.0425 ,,	.26″	.0533 ,,	1230 ,,
2000	.0425 ,,	.26″	.0533 ,,	1140 ,,
2500	.045 ,,	.265″	.0552 ,,	1180 ,,
3000	.045 ,,	.27″	.0574 ,,	900 ,,
3500	.045 ,,	.27″	.0574 ,,	980 ,,
4000	.045 ,,	.27″	.0574 ,,	1170 ,,
4500	.045 ,,	.28″	.0614 ,,	1080 ,,
5000	.045 ,,	.28″	.0614 ,,	980 ,,

TABLE 10. (FIG. IV.)

Comparative Test on Electrode Materials. Material "A."

$^3/_{16}$" Diameter tip. Included Angle 120°.

Welding current : 7,620 amps. Speed of Welding : 40 welds/min.
Electrode pressure : 10,000 lb./sq.in. Welding time : 10 cycles.
Water cooling : 1 gal./min./electrode.

No. of Welds	*Cont. Area sq. in.*	*Cont. Dia. in.*	*Tip Dia. in.*	*Imp. Dia. in.*	*Weld Dia. in.*	*Weld strength/spot taken from average of three welds. (1" overlap)*
0	.030	.196	.1875	.173	.185	993 lb.
250	.030	.196	.21	.173	.197	953 ,,
500	.0325	.204	.215	.173	.157	1000 ,,
1000	.0325	.204	.22	.173	.145	1085 ,,
2000	.0350	.211	.25	.177	.197	997 ,,
4000	.035	.211	.26	.193	.185	970 ,,
6000	.0425	.232	.27	.193	.197	995 ,,
8000	.045	.232	.285	.193	.197	1020 ,,
10000	.0475	.246	.310	.193	.197	1040 ,,
12000	.0550	.265	.320	.197	.197	1075 ,,
14000	.060	.276	.32	.197	.197	1160 ,,
16000	.065	.288	.325	.197	.197	1170 ,,
18000	.070	.298	.330	.197	.197	1020 ,,
20000	.0725	.304	.340	.205	.197	1130 ,,
22000	.0750	.309	.345	.205	.157	1000 ,,
24000	.0775	.314	.345	.205	.177	1055 ,,
26000	.0775	.314	.350	.205	.189	993 ,,
28000	.080	.319	.355	.205	.185	870 ,,
30000	.080	.319	.365	.205	.193	940 ,,
32000	.0850	.329	.370	.209	.193	1040 ,,
34000	.085	.329	.375	.209	.173	1060 ,,
36000	.0875	.335	.380	.209	.189	1000 ,,
38000	.0875	.335	.380	.209	.173	1050 ,,
40000	.0875	.336	.380	.209	.189	1170 ,,

TABLE 11 (FIG. IV).

Comparative Test on Electrode Materials. Material " B."

$^3/_{16}$ Diameter tip. Included Angle 120°

Welding current : 7,620 amps. Speed of welding : 40 welds/min.
Electrode pressure : 10,000 lb./sq. in. Welding time : 10 cycles.
Water cooling : 1 gal./min./electrode.

No. of Welds	*Cont. Area sq. in.*	*Cont. Dia. in.*	*Tip. Dia. in.*	*Imp. Dia. in.*	*Weld Dia. in.*	*Weld strength/spot taken from average of three welds.* (1" *overlap*)
0	.03	.196	.1875	.161	.189	1056 lb.
250	.0325	.204	.195	.161	.173	1120 ,,
500	.035	.211	.200	.161	.197	1133 ,,
1000	.035	.211	.210	.169	.198	983 ,,
2000	.0375	.218	.230	.173	.197	887 ,,
4000	.040	.225	.240	.181	.189	1266 ,,
6000	.040	.225	.255	.181	.194	1153 ,,
8000	.0425	.252	.265	.181	.157	1010 ,,
10000	.045	.239	.275	.181	.189	1030 ,,
12000	.0475	.246	.280	.181	.177	980 ,,
14000	.050	.252	.280	.181	.197	987 ,,
16000	.0525	.259	.285	.193	.197	1040 ,,
18000	.055	.265	.290	.197	.197	1163 ,,
20000	.055	.265	.290	.201	.197	935 ,,
22000	.0575	.271	.290	.201	.199	1000 ,,
24000	.0575	.271	.290	.205	.199	985 ,,
26000	.060	.276	.290	.205	.199	1215 ,,
28000	.060	.276	.290	.205	.201	975 ,,
30000	.060	.276	.290	.205	.199	965 ,,
32000	.060	.276	.290	.205	.193	960 ,,
34000	.060	.276	.290	.205	.197	1150 ,,
36000	.060	.276	.295	.205	.193	1000 ,,
38000	.0625	.282	.295	.205	.197	1040 ,,
40000	.0625	.282	.295	.205	.193	1100 ,,

TABLE 12 (FIG. V.)

The Effect of Varying Welding Current. Material "A."

$\frac{1}{4}''$ Diameter tip. Included Angle 120°.

Welding current : 9,220 amps. Speed of welding : 40 welds/min.
Electrode pressure : 10,000 lb./sq.in. Welding time : 10 cycles.
Water cooling : 1 gal./min./electrode.

No.of Welds	*Contact Area*	*Tip Dia.*	*Tip Area*	*Weld strength/spot taken from average of three welds. (1" overlap)*
0	.0400 sq. in.	.25"	.0491 sq. in.	1100 lb.
250	.0400 ,,	.26"	.0533 ,,	1320 ,,
500	.0425 ,,	.27"	.0574 ,,	1150 ,,
1000	.0425 ,,	.27"	.0574 ,,	1270 ,,
1500	.0450 ,,	.28"	.0614 ,,	1210 ,,
2000	.0450 ,,	.28"	.0614 ,,	1310 ,,
2500	.0450 ,,	.28"	.0614 ,,	1260 ,,
3000	.0475 ,,	.29"	.0660 ,,	1320 ,,
3500	.0500 ,,	.29"	.0660 ,,	1220 ,,
4000	.0525 ,,	.30"	.0706 ,,	1180 ,,
4500	.0525 ,,	.30"	.0706 ,,	1300 ,,
5000	.0550 ,,	.30"	.0706 ,,	1320 ,,

TABLE 13 (FIG. V.)

The Effect of Varying Welding Current. Material "A."

$\frac{1}{4}''$ Diameter tip. Included Angle 120°.

Welding current : 8,200 amps. Speed of welding : 40 welds/min.
Electrode pressure : 10,000 lb./sq.in. Welding time : 10 cycles.
Water cooling : 1 gal./min./electrode.

No.of Welds	*Contact Area*	*Tip Dia*	*Tip Area*	*Weld strength/spot taken from average of three welds. (1" overlap)*
0	.04 sq. in.	.25"	.0491 sq. in.	1140 lb.
250	.0375 ,,	.26"	.0533 ,,	1150 ,,
500	.0375 ,,	.27"	.0574 ,,	1040 ,,
1000	.0375 ,,	.27"	.0574 ,,	1140 ,,
1500	.0375 ,,	.27"	.0574 ,,	1120 ,,
2000	.0375 ,,	.27"	.0574 ,,	1220 ,,
2500	.0375 ,,	.27"	.0574 ,,	1310 ,,
3000	.0425 ,,	.28"	.0614 ,,	1220 ,,
3500	.045 ,,	.285"	.0639 ,,	1150 ,,
4000	.045 ,,	.285"	.0639 ,,	1130 ,,
4500	.045 ,,	.285"	.0639 ,,	1210 ,,
5000	.0475 ,,	.29"	.0660 ,,	1150 ,,

TABLE 14. (FIG. V.)

The Effect of Varying Welding Current. Material "A."

¼″ Diameter tip. Included Angle 120°

Welding current.: 7,620 amps. Speed of welding : 40 welds/min.
Electrode pressure : 10,000 lb./sq.in. Welding time : 10 cycles.
Water cooling : 1 gal./min./electrode

No. of Welds	*Contact Area*	*Tip Dia.*	*Tip Area*	*Weld strength/spot taken from average of three welds.* (1″ *overlap*)
0	.0400 sq. in.	.25″	.0491 sq. in.	1170 lb.
250	.0400 ,,	.25″	.0491 ,,	1000 ,,
500	.0400 ,,	.25″	.0491 ,,	1090 ,,
1000	.0425 ,,	.26″	.0533 ,,	1200 ,,
1500	.0425 ,,	.26″	.0533 ,,	1080 ,,
2000	.0425 ,,	.26″	.0533 ,,	1090 ,,
2500	.0425 ,,	.26″	.0533 ,,	1010 ,,
3000	.0425 ,,	.26″	.0533 ,,	1060 ,,
3500	.0425 ,,	.26″	.0533 ,,	950 ,,
4000	.0450 ,,	.26″	.0533 ,,	1000 ,,
4500	.0450 ,,	.26″	.0533 ,,	1050 ,,
5000	.0450 ,,	.26″	.0533 ,,	1030 ,,

TABLE 15. (FIG. VI.)

The Effect of Varying Welding Current. Material "A."

$^{3}/_{16}$″ Diameter tip. Included Angle 120°.

Welding current : 7,620 amps. Speed of welding : 40 welds/min.
Electrode pressure : 10.000 lb./sq.in. Welding time : 10 cycles.
Water cooling : 1 gal./min./electrode.

No. of Welds	*Contact Area*	*Tip Dia.*	*Tip Area*	*Breaking load of spot welds in lbs.* (1″ *overlap*)
0	.030 sq. in.	.1875″	.02765 sq. in.	993 lb.
250	.030 ,,	.21″	.0346 ,,	953 ,,
500	.0325 ,,	.215″	.0362 ,,	1000 ,,
1000	.0325 ,,	.22″	.0379 ,,	1085 ,,
2000	.0350 ,,	.25″	.0491 ,,	997 ,,
4000	.0350 ,,	.26″	.0533 ,,	970 ,,
6000	.0425 ,,	.27″	.0574 ,,	995 ,,
8000	.0450 ,,	.285″	.0639 ,,	1020 ,,
10000	.0475 ,,	.31″	.0755 ,,	1040 ,,

TABLE 16. (FIG. VI.)

The Effect of Varying Welding Current. **Material "A."**

$^3/_{16}$" Diameter tip. Included Angle 120°.

Welding current : 7,020 amps. Speed of welding : 40 welds/min.
Electrode pressure : 10,000 lb./sq. in. Welding time : 10 cycles.
Water cooling : 1 gal./min./electrode.

No. of Welds	*Cont. Area sq. in.*	*Cont. Dia. in.*	*Tip Dia. in.*	*Imp. Dia. in.*	*Weld Dia. in.*	*Weld strength/spot taken from average of three welds.* (1" *overlap*)
0	.030	.196	.1875	.173	.189	1070 lb.
250	.030	.196	.200	.173	.189	980 ,,
500	.030	.196	.210	.173	.189	1015 ,,
1000	.030	.196	.215	.173	.181	895 ,,
2000	.0325	.204	.222	.173	.192	935 ,,
4000	.0350	.211	.24	.177	.177	875 ,,
6000	.0375	.218	.253	.181	.173	885 ,,
8000	.0375	.218	.256	.181	.177	955 ,,
10000	.04	.226	.262	.181	.192	925 ,,
12000	.04	.226	.287	.193	.181	960 ,,
14000	.0425	.232	.300	.193	.185	950 ,,
16000	.045	.239	.310	.193	.177	920 ,,
18000	.045	.239	.312	.193	.177	1015 ,,
20000	.050	.252	.315	.193	.185	960 ,,
22000	.0575	.271	.315	.197	.208	950 ,,
24000	.060	.276	.318	.197	.189	1000 ,,
26000	.060	.276	.320	.197	.197	1050 ,,
28000	.0625	.282	.322	.197	.197	1000 ,,
31000	.0650	.288	.327	.197	.192	1025 ,,
33000	.0675	.293	.335	.197	.192	1075 ,,
35000	.070	.298	.34	.201	.189	1040 ,,
37000	.0725	.304	.345	.205	.181	1060 ,,
40000	.0725	.304	.347	.205	.181	960 ,,

TABLE 17. (FIG. VIII.)

The Effect of Varying Welding Pressure. Material "A."

$\frac{1}{4}''$ Diameter tip. Included Angle 120°.

Welding current : 9,220 amps. Speed of Welding : 40 welds/min.
Electrode pressure : 10,000 lb./sq.in. Welding time : 10 cycles.
Water cooling : 1 gal./min./electrode.

No. of Welds	*Contact Area*	*Tip Dia.*	*Tip Area*	*Breaking load of spot welds in lbs.* (1" *overlap*)
0	.0400 sq. in.	.25"	.0491 sq. in.	1100 ,,
250	.0400 ,,	.26"	.0533 ,,	1320 ,,
500	.0425 ,,	.27"	.0574 ,,	1150 ,,
1000	.0425 ,,	.27"	.0574 ,,	1270 ,,
1500	.0450 ,,	.28"	.0614 ,,	1210 ,,
2000	.0450 ,,	.28"	.0614 ,,	1310 ,,
2500	.0450 ,,	.28"	.0614 ,,	1260 ,,
3000	.0475 ,,	.29"	.0660 ,,	1320 ,,
3500	.0500 ,,	.29"	.0660 ,,	1220 ,,
4000	.0525 ,,	.30"	.0706 ,,	1180 ,,
4500	.0525 ,,	.30"	.0706 ,,	1300 ,,
5000	.0550 ,,	.30"	.0706 ,,	1320 ,,

TABLE 18. (FIG. VIII.)

The Effect of Varying Welding Pressure. Material "A."

$\frac{1}{4}''$ Diameter tip. Included Angle 120°.

Welding current : 9,200 amps. Speed of welding : 40 welds/min.
Electrode pressure : 7,500 lb./sq.in. Welding time : 10 cycles.
Water cooling : 1 gal./min./electrode.

No. of Welds	*Contact Area*	*Tip Dia.*	*Tip Area*	*Breaking load of spot welds in lbs.* (1" *overlap*)
0	.0425 sq. in.	.25"	.0491 sq. in.	1320 lb.
250	.0425 ,,	.26"	.0533 ,,	1330 ,,
500	.0425 ,,	.27"	.0574 ,,	1330 ,,
1000	.0450 ,,	.28"	.0614 ,,	1420 ,,
1500	.0450 ,,	.29"	.0660 ,,	1360 ,,
2000	.0450 ,,	.29"	.0660 ,,	1280 ,,
2500	.0475 ,,	.30"	.0706 ,,	1240 ,,
3000	.0475 ,,	.30"	.0706 ,,	1390 ,,
3500	.0475 ,,	.30"	.0706 ,,	1140 ,,
4000	.0475 ,,	.30"	.0706 ,,	1370 ,,
4500	.0475 ,,	.30"	.0706 ,,	1410 ,,
5000	.0500 ,,	.31"	.0755 ,,	1210 ,,

Research Department: Production Engineering Abstracts

(Edited by the Director of Research)

NOTE.—*The addresses of the publications referred to in these Abstracts may be obtained on application to the Research Department, Loughborough College, Loughborough.*

ACCOUNTING AND ADMINISTRATION

A Modern Method of Cost and Control Recording, by P. H. Billington. (*Mechanical World, November 13, 1942, Vol. CXII, No. 2915, p. 468, 8 figs.*).

Making every production document from an accurate master statement. Example of master sheet. Material issue ticket reproduced from master sheet. Control costing card. Progress advice note. Complete set of documents showing also master sheet from which they are reproduced.

ELECTRICAL ENGINEERING.

Watch your Control Equipment, by E. H. Alexander. (*The Machinist, November 7, 1942, Vol. 86, No. 30, p. 764, 2 figs.*).

Electric control equipment is an essential part of almost all modern production equipment. It should be inspected regularly. Temperature rise. Use of silver contacts. Brazing for better contact.

JIGS AND FIXTURES.

Jigs and Fixture Details—II and III, by John G. Jergens. (*The Machinist, November 7, 21, 1942, Vol. 86, Nos. 30, 32, pps. 768, 824, 28 figs.*).

Equalising devices. The equaliser has a combination of movable jaws which clamp the work in proper relation to the centre line. Variations. Use pins for internal work, V-slides for spherical work, or an inclined plane for raising the work horizontally. The equaliser serves the purpose of making allowance for slight variations in unfinished work and holding it in the proper position for machining. Thirteen examples are shown. Several types of standard details which can be used to advantage in the design of jigs and fixtures. The jig-leaf, the leaf stop, leaf clamp, and several methods for attaching a leaf which is to swivel. A clamping method for several round bars, and for a movable slide. A few indexing mechanisms are included.

MACHINE ELEMENTS.

Chain Drives, by H. Stuart Jude. (*Power Transmission, November 1942, Vol. II, No. 130, p. 465, 3 figs*).

A well-designed chain drive will deliver consistently good service under suitable operating conditions, and correct application is not difficult if the rules are obeyed. Roller type chain. Tooth type chain. Chain drives can be designed to suit widely varying conditions of service and, since chains cannot slip, long or short centre distances can be used in the full knowledge that every revolution of the driver will be transmitted to the driven wheel. Legitimate wear. Ratio and centre distance. The chain drive layout. Maintenance.

MACHINING, MACHINE TOOLS.

Measuring Metal Surfaces (Grinding), by L. H. Milligan. (*The Tool Engineer, September 1942, Vol. XI, No. 9, p. 82, 11 figs.*).

The abrasives in common commercial use consist of either crystalline alumina (aluminium oxide) or crystalline silicon carbide. Precision grinding is usually carried out with abrasive products of number 46 or finer grain size, and for extremely fine finishing, sizes as small as number 500 or 600 or even especially prepared materual such as levigated alumina may be employed. Abrasive operations : (1) ordinary grinding ; (2) fine grinding ; (3) honing ; (4) superfinishing ; (5) " hydrolapping " (6) sandpapering. Importance of surfaces. The mechanisms of wear : (1) cutting due to rough surfaces; (2) abrasion due to hard particles from the environment ; (3) corrosion by chemically active materials in the environment. (4) galling due to molecular forces between metals as modified by surface films ; (5) pitting due to fatigue cracking of promontories on surfaces. Surface characteristics. Standard surfaces.

Internal Grinding, by Allen E. Lepley. (*The Tool Engineer, September 1942, Vol. XI, No. 9, p. 86, 6 figs.*).

Internal grinders are of three basic types ; chucking machines, centreless internal grinders and planetary grinders. To determine the proper wheel for a given job : first ,consider the material to be ground. Second, the amount of stock to be removed, the accuracy, and the finish required. Third, the area of contact between the wheel and the work. Fourth, the condition of the grinding machine itself. Fifth, and finally the relation between the wheel and work speeds. Choosing the wheel dimensions. Coolants. Eleven basic jobs must be learned for successful operation of three types of internal grinders.

Centreless Grinding, by Gary F. Heckman. (*The Tool Engineer, September 1942, Vol. XI, No. 9, p. 92, 9 figs.*).

The principal elements of a centreless grinding machine are the grinding wheel, regulating wheel, and the work rest. Work and wheel centres. Achieving cylindrical form. Methods of centreless grinding. Through-feed. In-feed. Relation of factors. All centreless machines offer the following principal advantages : (1) The work is rigidly supported ; (2) no axial thrust is imposed on the work while grinding. (3) Less grinding stock is required, with correspondingly longer wheel life. (4) The possibility of error is reduced by half, because stock removal is measured on the diameter. (5) Error due to wheel wear is likewise reduced. (6) The machine requires only slight attention. (7) The grinding of the smaller size work can be assisted by use of a magazine, gravity chute, or hopper feeds.

A Positive Automatic Feed for Hones, by E. D. Ball. (*Machinery, November, 19, 1942, Vol. 61, No 1571, p. 576, 3 figs.*).

Section of the uni-directional clutch. Automatic trip-motion mounted to the column of the machine.

Milling Cutter Power Requirements, by O. W. Winter. (*The Tool Engineer, October 1942, Vol. XI, No. 10, p. 88, 14 figs.*)

The following variable factors effect the efficiency of a milling cutter or rather, the power required to drive a milling machine. (1) The efficiency of the machine and driving motor. (2) The material being milled. (3) The milling cutter design. (4) The nature of the cut. (5) The metal removal.

(6) The shape of the chips removed. (7) The cutting lubricant. (8) Condition of equipment. The project covers the following materials and cutters : (I) Cast iron—1. shell end mills ; 2. face mills ; 3. half side mills ; 4. spiral slab mills ; 5. slotting cutters ; (II) Nickel-chromium steel (SAE No. 3125, 3130, 3135 and 3140). (III) Cast duralumin. (IV) Wrought duralumin. Methods and general results.

MANUFACTURING METHODS.

Manufacture of Tungsten Metal, by P. E. Wretblad. (*Powder Metallurgy, edited by John Wulff, published by the American Society for Metals, chapter 38, p. 420.*)

Production of tungsten powder, pressing, sintering, fabrication of wire, additives to tungsten filaments.

(*Supplied by the British Non-Ferrous Metals Research Association*).

Hardened Gears without Grinding, by Frank W. Curtis. (*The Tool Engineer, October 1942, Vol. XI, No. 10, p. 94, 7 figs.*)

Induction hardening method saves finish grinding operation, permits tougher gears, saves alloy steel. The absence of scale or deformation, which is characteristic of this method, makes grinding unnecessary.

Fixing Bearing Metal in Steel Shells, by J. K. Anthony. (*Met. Progress, August 1942, Vol. 42, No. 2, p. 213.*)

A schedule of operations for casting low-tin bearing metals into the shell, given in response to a question raised by a manufacturer of fan bearings.

(*Supplied by the British Non-Ferrous Metals Research Association.*)

The Practice of Powder Metallurgy, by H. W. Greenwood. (*Met. Ind., October 9, 16, 1942, Vol. 11, Nos. 15, 16, pp. 226, 242*). (*In progress.*)

The beginning of a survey of the subject. First part gives a brief account of methods of preparing powders and second part deals with the influence of particle shape and size.

(*Supplied by the British Non- Ferrous Metals Research Association.*)

Shell Fuses by the Million. (*The Machinist, November 14, 1942, Vol. 86, No. 31, p. 202E, 33 figs.*)

Carburettor manufacturer has retooled multi-spindle automatics and fourteen station indexing machines to make percussion fuses. Special milling and drilling machines speed production.

The Walrus Amphibian, Part II. by F. C. Sheffield, (*Aircraft Production, December 1942, Vol. IV, No. 50, p. 710, 18 figs.*)

The production of the wings is described, as well as the assembly of typical control surfaces. The article concludes with a review of the methods employed in the manufacture of the fuel and oil tanks.

MATERIALS, MATERIAL TESTING

Properties of Nickel-Chromium Heat-Resisting Steel. " Engineering Properties of Heat-Resistant Alloys " by H. S. Avery, E. Cook and J. A. Fellows, (*Amer. Inst. Mining and Metallurgical Engineers, Tech. Publ. 1480, Metals Technology, August 1942.*)

The paper amplifies data presented in the authors' earlier publication (T. P. 1443) which dealt primarily with mode of testing. The second paper

comprises a very extensive study of steels of the 26-12 chromium-nickel type, with particular reference to their properties and performance over the range 1400°-2000°F. (760°-1092°C). The lines of the investigation were largely influenced by the requirements of the oil-refining industry. Its scope, and some of the main conclusions, are summarised below : Creep. Metallography. Effects of composition. Strength versus ductility. Thermal stresses. Stress-strain-rupture tests. Magnetic analysis.

(*Supplied by the Nickel Bulletin.*)

Some Dynamic Properties of Rubber, by C. O. Harris. (*J. App. Mech. Vol. 9, No. 3, September, 1942, p. 129.*)

The purpose of the investigation described in this paper was to obtain information concerning the dynamic properties of rubber bonded to metal. Two properties of rubber were measured (*a*) the internal damping, and (*b*) the dynamic modulus of elasticity. Two types of specimens were tested, (*a*) rubber cylinders bonded to steel cylinders at the ends and stressed in compression, and (*b*) specimens of rubber bonded to steel and stressed in shear. All specimens were of the same stock, 5140-V-4, manufactured by the U.S. Rubber Company. The hardness, as measured by the durometer, varied from 32 to 40. In the process of bonding to the steel, a $^1/_{32}$-in. layer of 60 durometer stock was added adjacent to each piece of steel. This represents standard practice of the U.S. Rubber Company in bonding soft stock to metal. All specimens were cured for 30 min. at 279°F.

(*Supplied by D.S.R., Ministry of Aircraft Production.*)

Researches on replacement materials with special reference to Al conductors in electrical machinery, by K. Sachs and W. G. Noack. (*Review Brown Boveri, Switzerland, Vol. 29, No. 1-3, Jan.-March, 1942, pp. 78-83*).

The introduction of Al wiring in electrical machinery has been delayed not so much by its reduced conductivity but by difficulties associated with corrosion and soldering or brazing. Extensive practical experience has shown that corrosion difficulties can be overcome by choice of composition of alloy combined if necessary with either anodic treatment or painting.

Soldering or brazing of Al is perfectly feasible, provided care is taken to remove either chemically or mechanically all traces of oxide. In this connection reference is made to the so called "rubbing" solders for securing a tin deposit. Messrs, Brown Boveri have developed a method of welding Al wire electrically without the need of either flux or welding wire. As many as 24 separate wires. each one mm. diameter can be welded together, the joint being stronger than that obtained with any kind of solder. For this reason electric or flame welding should be used whenever possible. Terminal connections on Al wires are made by means of special copper clad Al connectors. A short length of the cladding is removed chemically at one end and the bare Al welded electrically to the Al conductor. The other (cladded) end can be soldered normally.

Details of Al stator windings of a 20,000 KW alternator are given and it is stated that one 100,000 Al squirrel cage motors ranging up to 15 KW have been delivered in the last few years.

In addition to the utilisation of Al in the electrical industry, the authors briefly review advances made in the welding of high alloy steels, with special reference to turbine blading.

(*Supplied by D.S.R., Ministry of Aircraft Production.*)

MEASURING METHODS AND APPARATUS

Quality-Control Procedures in Ordnance Inspection, by G. D. Edwards. (*Mechanical Engineering, September, 1942, Vol. 64, No. 9, p. 673.*)

Perfection in mass production. Inspection fatigue. Quality risks in mass production. Proper use of quality-control procedures. Encouraging manufacturers to control quality. Elegibility for reduced acceptance inspection. Quality-control procedures must be tailor-made. Decentralizing the introduction of control procedures. American emergency standards for quality control. Inspirational conferences for ordnance inspection personnel.

X-Ray Measurement of the Thickness of the Cold-Worked Surface Layer Resulting from Metallographic Polishing, by H. C. Vacher. (*J. Res. Nat. Bur. Stand., Aug. 1942, Vol. 29, No. 2, p. 177.*)

Cu, Al and steel specimens, each originally having a surface free from cold work, were finished with various abrasives commonly used for metallographic polishing. The thicknesses of the layers altered by these abrasives treatments were determined by means of X-ray back-reflection patterns. Results show that this method can be used for determining the thickness of cold-worked layers between 2 and 42 microns on Cu, 2 and 95 microns on Al and 2 and 25 microns on steel (a micron is one-thousandth of a millimeter).

(*Supplied by the British Non-Ferrous Metals Research Association.*)

Methods of measuring the thickness and porosity of metallic coatings. by Abner Brenner. (*Sheet Metal Industries, December 1942, Vol. 16, No. 188, p. 1861.*)

The methods of measuring the thickness of metallic coatings may be divided into two classes : (1) Those which measure the average thickness on a given area, and (2) those which measure the thickness at a given point—that is, the local thickness. I. Method of measuring average thickness. Chemical method. Quantitative stripping methods. Stripping (1) nickel coatings ; (2) copper coatings ; (3) chromium coatings. (4) zinc or cadmium from steel ; (5) hot dipped tin coatings from steel ; (6) silver from brass. II. Methods of measuring local thickness : (a) microscopic. (b) chord method. (c) dropping test. (d) Preece test. (e) jet method. (f) tests for chromium.

Heat Treating and Inspection of Metals, (*U. S. War Department Tech. Manual 1-423, September 1942.*)

General principles of heat treatment ; equipment ; general and specific heat treatment of steels and alloy steels ; heat treatment of Alcoa Al alloys ; hardness testing and equipment ; magnaflux inspection.

(*Supplied by the British Non-Ferrous Metals Research Association.*)

Process Lags in Automatic Control Circuits, by J. G. Ziegler and N. B. Nichols, A.S.M.E. (*U.S.A., October Meeting, 1942.*)

1. In the application of automatic controller, it is important to realize that controller and process form a unit ; credit or discredit for results obtained are attributable to one as much as the other.

2. The chronology in process design is often wrong. Generally an engineer first designs his equipment so that it will be capable of performing its intended function at the normal throughput rate plus a factor of safety. The control engineer or instrumentman is then told to put on a controller capable of maintaining the static equilibrium for which the apparatus was designed.

3. A long expensive process of "cut-and-try" is often necessary in order to make the equipment work. Both engineers realize that some factor in

equipment design was neglected but generally they can neither identify the missing ingredient nor correct it in future design.

The missing characteristic can be called "controllability," the ability of the process to achieve and maintain the desired equilibrium value. Design for steady-state conditions is not enough if exact maintenance of variables is necessary. Control action consists of continuous correction of process changes tending to destroy equilibrium at the desired value and, as such, its study involves not steady-state but transient characteristics of the process and controller.

4. Methods are given for quantitative determination of time lags in automatically controlled processes. The area under recovery curves is taken as a direct measure of process difficulty, and this area is shown to vary as the second power of the time lag. A "recovery-factor" term, part of a complete expression for controllability, is introduced which makes possible a classification of processes in dimensions of the process itself, regardless of controller or valve mechanism used. Values of this recovery factor from various industrial applications are given in tabular form. Several processes are examined for the time lag, and means of reducing this unfavourable characteristic are demonstrated. It is felt that this paper will be useful to engineers who are interested in improving the controllability of the processes which they design.

(*Supplied by D.S.R., Ministry of Aircraft Production.*)

METALLURGY OF IRON AND STEEL

Wartime Gear Steels, by E. F. Davis, "National Emergency Gear Steels," (*Iron Age, 1942, Vol. 150, August 6, p. 45, August 13, p. 58*).

The first part of the article traces the recent U. S. standardisation activities as related to "alternate" steels for gears, and gives particulars of steels of the N. E. 8000 and A series, which have been proposed as substitutes for regular S. A. E. and A. I. S. I. gear steels. Part 2 of the article covers a review of the properties of the N. E. 4000 series (formerly known as Amola steels), as affecting their use for gears.

(*Supplied by the Nickel Bulletin*).

PLASTIC MATERIAL.

Some Recent Advances in Industrial Plastics, by W. G. Wearmouth. (*J. Sci. Instruments, September 1942, Vol. 19, No. 9, p. 129.*).

Survey of newly developed plastics and their uses. Includes a table of trade names, compositions, available forms and physical and mechanical properties.

(*Supplied by the British Non-Ferrous Metals Research Association*).

The Design of Plastic Moulded Parts for Economical Quantity Production. (*Machinery, November 26, 1942, Vol. 61, No. 1572, p. 599, 19 figs*).

The subject is concerned with the design of the parts to be produced, with special attention to those details which are essential to satisfactory moulding. Examples : (1) A moulding with an external under-cut which requires a loose piece or a side core in the mould ; (2) a moulding which indicates where sharp corners should be avoided and where used to advantage. A radio cabinet with well rounded corners that facilitate moulding. A moulding having an irregular parting. Ball knob with a bead moulded at the parting. The flash is easily removed. Luggage handles moulded hollow in two halves that are subsequently cemented together. A telephone mouthpiece. Mould and moulding in which a side core is required to form a hole in the side wall.

Moulding with offset wall. Typical moulding in which the draught is on the inside only. Typical beaker which has a draught both inside and outside. Bad and good practice in designing bosses for fastenings.

Plastics for Aircraft Construction, by H. Stener. (*Flugsport, Germany, Vol. 34, No. 21, October 14, 1942, p. 315.*)

Of the 2 main classes of plastics, viz., thermoplastic and thermosetting, the latter are of principal interest to the aircraft constructor on account of their better mechanical properties.

In German literature, thermosetting plastics are known as synthetic resins (Kunstharze), and the author describes the principal methods of moulding such products under pressure. After manufacture, the parent plastic is in the so called state A and contains a considerable amount of moisture, some which is next driven off, the powdered product then being in the so called sensitive state B. This moulding powder is mixed with a filler (usually wood flour) and sprinkled into a metal die kept at about 160°C. The pressure applied and time of contact depend on the shape and size of the required article and vary from 150 to 1,200 atmosphere and 1-6 minutes.

Under these conditions, the resin powder first melts and then resolidifies (irreversible change), passing into the final hard C state.

If the finished article has to be machined out of the solid (plate or rod), it is advisable to use a plastic containing a fabric filler. The fabric (linen or flax) is first impregnated with resin in state " A " dissolved in alcohol. Subsequent heating and drying (atmospheric pressure) converts the resin into the sensitive state B. A number of layers of the heated fabric are then superposed and subjected to a pressure of about 100 atmospheres between heated plates (180°C.). Whilst the pressure moulding described previously only occupies a few minutes, the laminated plate is compressed for a period varying between 2 and 28 hours, before the resin has completely passed into the final hard state C.

Rods and tubes can also be manufactured by the continuous extrusion process. In this case, however, a fabric filler is unsuitable and wood flour or paper cuttings must be employed, leading to a reduction in strength.

The thermal co-efficient of expansion of plastic material is about twice that of light alloys and 4 times that of steel. This requires careful consideration in composite structure.

The author gives examples of aircraft fittings made of plastics and employed on a large scale (bushing, bearings, pulley wheels, knobs, handles, lightly loaded gears, etc.).

Experiments are in progress for moulding major structural elements of aircraft (control surfaces, wing surfaces, fuselage shell, etc.), but so far success has only been achieved by the use of plywood as a base. Such structures are thus rather made of treated plywood than of synthetic resin proper. It seems probable that small aircraft can be built profitably in this manner and that the method will be extended to larger sizes after more experience has been gained.

(*Supplied by D.S.R., Ministry of Aircraft Production.*)

RESEARCH.

Metallic Wear of Metals and Alloys, by J. W. Donaldson. (*Metallurgia, September 1942, Vol. 26, No. 155, p. 155*).

Describes recent research on the mechanism of and factors affecting wear (with bibliography), and discusses the development and selection of new wear resisting alloys or the treatment of existing alloys to improve resistance to wear under service conditions.

(*Supplied by the British Non-Ferrous Metals Research Association*).

RETAILING.

Scrap Identification Tests : Reference tables of Rapid Scrap Identification Tests, (*Metals and Alloys, August, 1942, Vol. 16, p. 264*).

In view of the present possibility of inadvertent mixing of scrap, and of the need for rapid and accurate differentiation and sorting, the editors of Metals and Alloys have compiled three series of reference tables showing behaviour, in various test conditions, of materials which may be encountered as " scrap ". The data have been compiled from information given by Climax Molybdenum Corp.; International Nickel Co.; Inc., Linde Air Products Co.; Nassau Smelting and Refining Co. ; Norton Co.

(*Supplied by the Nickel Bulletin*).

SHOP MANAGEMENT.

Control of Production, by F. A. Carey. (*Aircraft Production, December, 1942, Vol. IV, No. 50, p. 724, 1 fig.*).

Process layout. Manufacturing procedure. Initial batches. Manufacture of units. A typical planning and progress chart for the production of a centre fuselage section. Time of changeover. Standardisation of working hours. Progress record. Rectifications. Applicability of modifications. Classification of labour.

SMALL TOOLS.

Tipped H.S.S. Tools, by Leo J. St. Clair. (*The Engineer, November 20, 1942, Vol. CLXXIV, No. 4532, p. 417, 7 figs.*).

Most machine shops have experienced breakage of solid high-speed steel tools. This breakage usually occurs on cutting tools of special shape, such as are used to machine a small section inside diameters or grooves. Example : part to be undercut. The solid 18-4-1 high speed steel tool which had a tendency to break. A tool tipped with an 8 per cent. cobalt H.S.S. whose breakage has been eliminated. Six-tipped circular form tool used to replace a solid H.S.S. form tool that frequently broke. The tipped tool uses less than 1 per cent. of the original material. Troublesome breakage of dove-tail form tools is eliminated by brazing a H.S.S. plate on a low-alloy shank in which the sharp dove-tail is cut. Tipped planer tool used to make a deep recess nor only saves scarce material but also reduces costly breakage.

Recommended Tap Drill Sizes—I and II. (*The Machinist, Reference Book Sheet, November 28, 1942, Vol. 86, No. 33, p. 849.*).

American national coarse-thread series. Size of thread. Threads per inch. Minor diameter of nut. Stock drills for 100 to 50 per cent. of basic thread depth.

Punches Cut their own Dies, by John Haydock. (*The Machinist, November 21, 1942, Vol. 86, No. 32, p.815, 6 figs*).

In this method of diemaking, the finished punch is mounted in the press with the roughed out die. The shearing action of the punch completes the die contour. A fine ribbon of metal is shaved from the die by the punch. In working on dural sheet the die is made of Kirksite A. Steps in making simplified dies for dural or alclad parts at Lockheed. Rubber strippers are inexpensive and quickly installed. They are usually applied to both the punch and the die. Steps in making simplified dies for SAE 4130 and stainless steel parts at Lockheed.

Diamond Abrasive Wheels. (*Machinery, November 19, 1942, Vol. 61, No. 1571, p. 567, 1 fig*).

Diamond wheel specifications. Selecting the wheel. Recommended operations. Dressing, truing and forming. Other points of importance.

SURFACE, SURFACE TREATMENT

The Formation and Evaluation of Zinc Coatings, Part VI—Corrosion. (*Sheet Metal Industries, December 1942, Vol. 16, No. 188, p. 1850, 10 figs*).

Factors which may influence corrosion. Effect of different waters. Effect of impurities. Effect of acidity on corrosion. Effect of different atmospheres. Electrolytic corrosion. The porosity of the coating. Effect of temperature.

The Trend of Electroplating Development, by S. Wernick. (*Abridged version in Met. Ind., October 16, 1942, Vol. 61, No. 16, p. 249.*).

Outlines developments up to the outbreak of war, the role of electroplating in the war and probable post-war developments. Among these latter he considers that some good effects of the war will be that industry will be used to working to specifications, factories will have their own plating departments instead of sending this work out and there will be improvements in plant, general procedure and technical education of workers.

Rust Proofing Cadmium Plated Tubular Parts, by B. Gross. (*Iron Age, July 30, 1942, Vol. 150, No. 5, p. 52*).

In America Cr-Mo steel tubular structures closed by welding and plated externally with Cd are usually given an internal coating of linseed oil through specially drilled holes which are subsequently plugged; this is done with a view to preventing corrosion. Corrosion tests described here show that not only is this linseed oil treatment unnecessary, but that it actually causes increased corrosion.

(*Supplied by the British Non-Ferrous Research Association*).

Surface Finish of Journals (effect on friction, wearing-in and seizure), by R. W. Dayton, and others. (*Mech. Eng., Vol. 64, No. 10, p. 718.*)

Tests to study surface finish of journals as affecting friction wearing-in, and seizure of bearings were made on an Amsler machine under the conditions given in this paper. Fine finishes were studied, the roughest having a profilometer reading of only 10 microinches.

It was found that there was rather good correlation between the seizure results and the product of profilometer readings taken in the axial and circumferential directions. Those surfaces having higher roughness-product readings had greater seizure tendency. This was approximately true irrespective of the finishing methods employed, which included grinding, sandpapering, loose-abrasive lapping and lapping with bonded abrasive wheels, but sandpapered surfaces gave rather better than average seizure resistance and loose-abrasive-lapped surfaces rather poorer than average seizure resistance. However, a loose-abrasive-lapped surface finished by ring lapping, and therefore exceptionally free from chatters and other defects, gave exceptionally good results when extremely fine abrasive paper was used lightly to finish its surface before testing.

The seizure results of all specimens also correlated well with the appearance of taper sections of the surfaces.

A study by means of taper sections and photomicrographs of the mechanism of wearing-in showed that the surfaces which wore-in most readily had a very

fine-scale roughness sometimes referred to as "fuzz." This fuzz is not indicated to be harmful on a journal which has a sufficiently fine surface finish as to have a reasonably high initial seizure resistance.

One effect that takes place during wearing-in was shown to be an extremely minute smoothing of the topmost part of the surface roughness, and this produced a large change in the frictional characteristics. The actual area of contact is thus indicated to be only a small percentage of the conventionally calculated area even for the finely finished and accurate surfaces being dealt with in this investigation. Trueness and large-scale roughnesses such as waviness, flat spots, and grinding chatter are also probably very important.

(*Supplied by D.S.R., Ministry of Aircraft Production.*)

WELDING, BRAZING, SOLDERING.

How to Weld Substitute Steels, by Harold Lawrence. (*Sheet Metal Industries December 1942, Vol. 16, No. 188, p. 1925, 3 figs*).

Influence of the common alloying elements on the hardenability of the heat affected weld zone in low alloy steels. Approximate influence of carbon content on the tensile properties of carbon steels in the as-rolled condition. Joint design as it influences physical properties.

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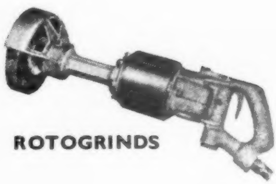
PNEUMATIC TOOLS



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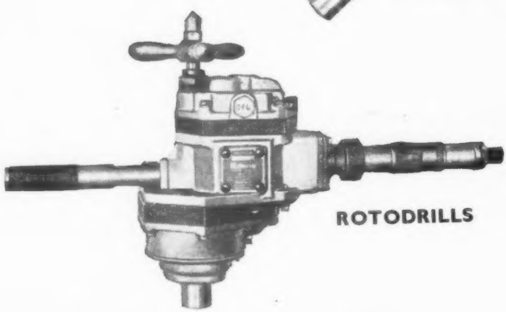

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